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COMPARISON OF HUMAN RESPONSES TO PROTOTYPE AND STANDARD UNIFORMS USING THREE DIFFERENT HUMAN SIMULATION MODELS: HSDA, SCENARIO_J AND SIMULINK2NM

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The human thermal physiological responses of Soldiers in three new prototype clothing systems under development were compared to responses in the current standard duty uniform (STDU) with body armor (BA) and load bearing equipment (LBE) while engaged in the same activities and environments. The prototype uniforms in the comparison were the Scorpion A, Scorpion B, and Concept2005 (C2005). C2005 was evaluated with and without clothing ventilation provided by its battery powered fan. The comparisons also include the effects of the clothing system on the Soldier with and without chemical biological defense gear (CBD).
The Soldier's responses were determined by simulation using 3 different well accepted thermo physiological computer models. The models: 1) USARIEM Heat Strain Decision Aid (HSDA version 7; 2) USARIEM SCENARIO_J (version 1.0b); and 3) Simulink 2 Node Model (SimuLink2NM), are described in the following Methods section.

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USARIEM TECHNICAL REPORT T05-08

COMPARISON OF HUMAN RESPONSES TO PROTOTYPE AND STANDARD
UNIFORMS USING THREE DIFFERENT HUMAN SIMULATION MODELS: HSDA,
SCENARIO_J AND SIMULINK2NM

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EXECUTIVE SUMMARY

The human thermal physiological responses of Soldiers in three new prototype clothing systems under development were compared to responses in the current standard duty uniform while engaged in the same activities and environments. The prototype uniforms in the comparison were Scorpion A, Scorpion B, and Concept2005. The comparison also includes the clothing with and without chemical biological defense gear. The Soldier's responses were determined by simulation using the following 3 different thermo physiological computer models: 1) Heat Strain Decision Aid (HSDA version 7); 2) SCENARIO_J (version 1.0b); and 3) Simulink 2 Node Model (SimuLink2NM).

Each model simulated physiological responses to 3 environments: desert (48.9°C, 20% relative humidity), jungle (35.0°C, 75% relative humidity) and temperate (35.0°C, 50% relative humidity). For each environmental condition and with each model, the comparisons were made for 3 levels of Soldier activity with metabolic rates of 150 watts (W) (e.g., driving, standing and filling), 250W (e.g., slow walk, seated with heavy arm movements) and 425W (e.g., fast walk, tennis singles). The simulated responses to the continuous activities were for 6 hour durations in full sun.

The simulated responses to a given condition and activity were a little different for each model but the response trends and conclusions were very similar. The summer desert, jungle and temperate conditions of the tests have air temperatures close to or greater than skin temperature which reduces dry heat loss to about zero and even results in a dry heat gain for the desert. Thus the Soldier in these conditions depends completely on the evaporation of sweat for thermoregulation and survival. These results show that sweat evaporation has progressively been improved with the prototype designs. Overall, the incremental clothing design changes have resulted in corresponding human response benefits for the conditions tested. That is, less elevated body temperatures, longer exposure times, lower heart rates and less water loss. Some of the benefits result from clothing weight reductions, permitting the Soldier to move about with less metabolic energy expenditure.

INTRODUCTION

The human thermal physiological responses of Soldiers in three new prototype clothing systems under development were compared to responses in the current standard duty uniform (STDU) with body armor (BA) and load bearing equipment (LBE) while engaged in the same activities and environments. The prototype uniforms in the comparison were the Scorpion A, Scorpion B, and Concept2005 (C2005). C2005 was evaluated with and without clothing ventilation provided by its battery powered fan. The comparisons also include the effects of the clothing system on the Soldier with and without chemical biological defense gear (CBD).

The Soldier's responses were determined by simulation using 3 different well accepted thermo physiological computer models. The models: 1) USARIEM Heat Strain Decision Aid (HSDA version 7; 2) USARIEM SCENARIO_J (version 1.0b); and 3) Simulink 2 Node Model (SimuLink2NM), are described in the following Methods section.

<center>**METHODS**</center>

SIMULATION MODELS

HSDA

      The HSDA is an empirical model developed at USARIEM from extensive laboratory and field testing to predict heat strain responses of Soldiers (6). Figure 1 shows the schematic of the HSDA model. The model primary inputs include environment (air temperature (Ta), relative humidity (RH), wind speed (wind), solar load (SL)), clothing characteristics (insulation, vapor permeability), metabolic rate of work-rest cycles, subject characteristics (height, weight) and acclimatization status. Given an individual's specified environmental and operational conditions, the model predicts core temperature (Tcr), sweat rates, and associated water requirement over specified time periods. The detailed principles of the model are described by Pandolf et al., (6).

<center>**Figure 1. Schematic of HSDA model**</center>

Input

Output

Environment
Ta,RH,wind,
SL,time

Empirical relations& algorithms

Tcr

Sweat

Human

weight,
height,
clothing,
metabolic rates,
external work
acclimation status
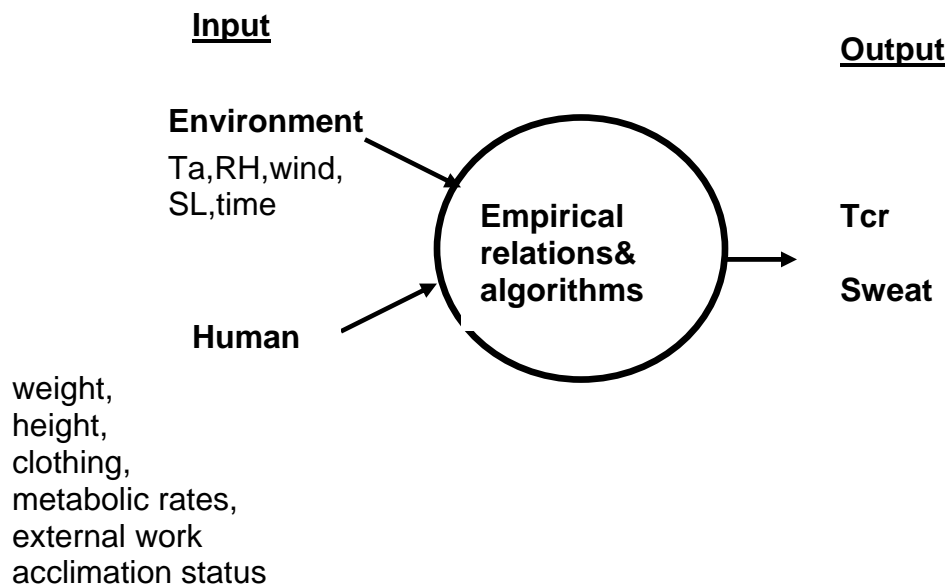
SCENARIO_J

      SCENARIO_J is the Java language version of the SCENARIO thermo physiological model developed at USARIEM by Kraning and Gonzalez (3). It is a rational human thermoregulation model based on first principles of physiology, heat transfer and thermodynamics. The model represents the human as six lumped parameter tissue compartments (Figure 2). Five of which are concentric layers representing core, muscle, fat, vascular skin and outer skin. The sixth compartment is

blood which interacts and exchanges heat directly with all of the compartments except the outer skin. At activities above resting, the increased energy is generated in the muscle compartment. The environment exchanges heat and moisture through the clothing and exposed skin and also exchanges heat and moisture with the core through respiration.

Figure 2. Schematic of SCENARIO
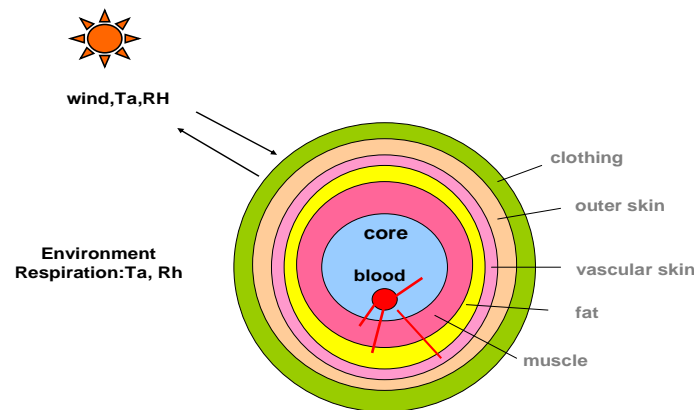
At rest, the core is the principle source of metabolic heat. This heat flows by conduction to the surrounding muscle compartment, by convection with blood that distributes the heat to the other compartments and by respiration. With exercise, heat from working muscles predominates and can be more than 10 times that of the core. The physiology and heat transfer principals and properties are based on extensive laboratory experiments from the literature and USARIEM. The main mechanisms for active physiological body temperature control are in regulating sweating, shivering and blood flow to the skin.

Simulink2NM

This model is an adaptation of the popular Gagge (1,2) model to the Simulink modeling system architecture. The Gagge model is similar to SCENARIO_J but simpler which the human represented as two physiological compartments (core and skin). It is also a simplification of the 41 compartment Stolwijk model (7). All of the metabolic activity (M) takes place in the core compartment (Figure 3).

Figure 3. Schematic of Simulink2NM
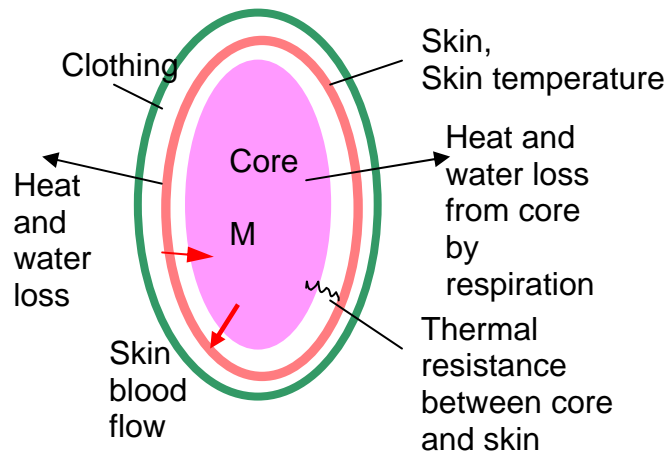
CLOTHING SYSTEMS

The clothing systems tested, and their weight and heat and mass transfer properties are given in Table 1. The uniform notations BA and LBE stand for body armor and load bearing equipment. The clothing weights and properties include the helmet. The heat and vapor resistance values are obtained from manikin tests reported by Giblo (unpublished, 2002) and Matthews (unpublished, 2002). The simulations were done for clothing systems with and without the addition of CBD. The C2005 ensemble has a small battery powered fan that can ventilate the clothing of the torso region with 10 ft^3/min (5 L/s) of outside air. With the fan running it is designated as: C2005 + 10cfm.

The relevant equations to determine total thermal (Clo) and vapor resistance (Im) of the clothing and the related dry and evaporative heat loss equations are described in Table 2. The gamma values, which adjust for the effects of wind velocity on insulation (Clo_gamma) and evaporative cooling (I_m/Clo_gamma), range from -0.06 to -0.23 and 0.12 to 0.42 respectively.

Table 1. Clothing properties

Uniform	Weight (kg)	Total Clo @ 1m/s	Total Im/Clo @ 1m/s
STDU+BA+LBE	13.00	1.45	0.29
STDU+BA+LBE+CBD	15.40	2.20	0.10
Scorpion A	10.84	1.26	0.32
Scorpion B	10.84	1.38	0.28
Scorpion B+CBD	11.97	1.70	0.16
C2005	10.84	1.64	0.31
C2005+CBD	11.97	1.92	0.25
C2005+10cfm	10.84	1.46	0.41
C2005+10cfm+CBD	11.97	1.61	0.36

Table 2. Summary of equations used to calculate Clo and Im resistances (Res) and dry and evaporative heat loss

Measurements	Equation	Unit
I. Thermal resistance at v(m/s) Res(v)	Clo(v)= Clo(@1m/s) * v^(Clo_Gamma)	Clo
	Res(v) = 0.155*Clo(v)	m^2°C/w
where		
1Clo = 0.155 °Cm^2/w		
II. Vapor resistance at v(m/s)	VRes(v)=.155/(LR*(Im/Clo(v))	m^2Torr/w
Where		
Im/Clo(v)=[Im/Clo@1m/s)] * v^(Im/Clo_Gamma)		
LR is Lewis Relation = 2.2 °C/Torr		
III. Dry heat loss from skin	Qdry = (Tsk-To)/Res(v)	w/m^2
Where		
Tsk = skin temperature in °C		
operative temperature, To=(hc*Ta+ hr*Tmr)/(hc+ hr)		
hc = convective heat transfer coefficient		
hr = radiative heat transfer coefficient		
Ta = air temperature in °C		
Tmr = mean radiant temperature in °C		
IV. Evaporative heat loss from skin	qevap = wet*(Psk - Pa)/VRes(v)	w/m^2
Where		
Wet = fraction of skin covered with water		
Psk = saturated vapor pressure at skin temperature (kPa)		
Pa = ambient water vapor pressure at skin temperature (kPa)		

METABOLIC RATES

The clothing systems had substantially different weights (Table 1). The STDU + BA + LBE system weighs 13 kg (28.6 lbs) while the new Scorpion designs are lighter at 10.84 kg (23.8 lbs). When these systems are outfitted with CBD gear the weights increase to 15 kg (33 lbs) for the STDU system but only to 11.97 kg (26.3 lbs) for the Scorpion. The metabolic effort necessary for a particular marching activity is directly related to the soldier's weight and the weight of his clothing. Thus the metabolic effort of a person marching at a given speed will be higher in heavier clothing systems than in lighter ones.

The walking speeds and terrain factors were selected using the Pandolf equation (5), to result in metabolic rates of 150, 250 and 425 watts (W) for a 70 kg (154 lbs) Soldier wearing the STDU ensemble. The terrain factors for desert, temperate, and jungle conditions were selected as 2.0, 1.2, 1.2, respectively (5). The grade was 0% for all the comparisons. For example in this way, the walking speed for a metabolic rate of 150W while wearing STDU under the desert weather was calculated as 1.43 km/h. The walking speed for 425W in the same STDU under the temperate or jungle condition was calculated as 5.22 km/h.

The metabolic rates for the other clothing systems were determined for the Soldier walking at the same speed, grade, and terrain but with the weight of the specific clothing ensemble worn. The resulting metabolic rates for the non-CBD and CBD clothing system are given in Table 3. Since the prototype clothing systems tested weigh less than the STDU, they require less metabolic effort for the same activity.

Table 3. Metabolic Rates (M, watts) calculated from walking speeds and clothing weights

Non-CBD equipped

Condition		Walking speed	(km/h)	
Desert		1.43	2.96	4.43
Temperate & Jungle		1.85	3.48	5.22
Uniform	Weight (kg)	Low M	Medium M	High M
STDU+BA+LBE	13.00	150	250	425
Scorpion A	10.84	147	245	415
Scorpion B	10.84	147	245	415
C2005	10.84	147	245	415
C2005+10cfm	10.84	147	245	415

CBD Equipped

Condition		Walking speed	(km/h)	
Desert		1.36	2.63	3.97
Temperate & Jungle		1.76	3.39	5.12
Uniform	Weight (kg)	Low M	Medium M	High M
STDU+BA+LBE	15.40	150	250	425
Scorpion B	11.97	145	241	409
C2005	11.97	145	241	409
C2005+10cfm	11.97	145	241	409

ENVIRONMENTAL CONDITIONS

Simulations were for sunny summer environments designated as: desert, jungle, and temperate. The sun effects were modeled to raise the mean radiant temperature (MRT) 20°C above air temperature (Ta). The wind speed was 1m/s for all tests reported here. The simulation conditions of the three environments are defined in Table 4 below:

Table 4. Environmental conditions for the simulations

Environment	Ta °C (°F)	MRT °C (°F)	Relative Humidity %	Dew Point °C (°F)	Wind Speed m/s (mph)
Desert	48.9 (120)	68.9 (156)	20	20 (68)	1.1 (2.2)
Jungle	35.0 (95)	55.0 (131)	75	30 (86)	1.1 (2.2)
Temperate	35.0 (95)	55.0 (131)	50	23 (73)	1.1 (2.2)

RESULTS

The Soldiers were simulated to enter the test environments starting from the same thermally neutral (comfort) state with a Tcr of 37°C and a resting heart rate (HR) of 70 bpm. The time for Tcr to rise to 38.5, 39.0 and 39.5 °C in the three environments and with same activities that produce metabolic rates of 150, 250 and 425W when wearing the STDU are given in Tables 5, 6 and 7 for non-CBD and CBD equipped clothing ensembles. The tables show the results from each of the three simulation models. Each table has parts D, J and T for desert, jungle and temperate environments. Tables 5D, 5J and 5T give the time for Tcr to reach 38.5°C, and Tables 6 and 7 give the time to reach 39.0 and 39.5°C respectively. The exposure time limits or times to reach a particular core temperature are generally longer for the new prototypes and particularly so for those with forced clothing ventilation (+10cfm).

The time responses of Tcr, HR, total water loss and physiological strain are graphed in Figures 4-11 and discussed for the various clothing systems, activities and environments.

Table 5D. Time for core temperature to reach 38.5°C under various ensembles and activities in hot desert environment (The units are minutes.)

Non CBD Uniform	150W equivalent metabolism				250W equivalent metabolism				425W equivalent metabolism		
	HSDA	SCENARIO_J	Simulink2NM		HSDA	SCENARIO_J	Simulink2NM		HSDA	SCENARIO_J	Simulink2NM
STDE+BA+LBE	94	102	80		50	57	39		31	30	21
Scorpion A	92	111	80		52	60	39		31	32	21
Scorpion B	N/A	N/A	71		N/A	N/A	37		N/A	N/A	21
C2005	147	184	138		57	76	47		33	35	21
C2005+10cfm	>300	>360	>360		64	99	66		34	37	25

CBD Uniform	150W equivalent metabolism				250W equivalent metabolism				425W equivalent metabolism		
	HSDA	SCENARIO_J	Simulink2NM		HSDA	SCENARIO_J	Simulink2NM		HSDA	SCENARIO_J	Simulink2NM
STDE+BA+LBE+CBD	67	54	43		41	39	27		25	26	17
Scorpion B +CBD	71	600	47		43	42	29		27	27	17
C2005+CBD	116	123	86		54	63	39		31	33	21
C2005+10cfm+CBD	>300	>360	>360		64	93	51		35	38	23

N/A = not available

Table 5J. Time for core temperature to reach 38.5°C under various ensembles and activities in hot jungle environment (The units are minutes.)

Non CBD Uniform	150W equivalent metabolism			250W equivalent metabolism			425W equivalent metabolism		
	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM
STDE+BA+LBE	122	117	85	53	60	37	30	31	20
Scorpion A	139	132	82	55	65	38	32	32	20
Scorpion B	N/A	N/A	75	N/A	N/A	37	N/A	N/A	20
C2005	215	153	93	57	70	41	32	33	20
C2005+10cfm	>300	255	164	61	79	47	33	34	22

CBD Uniform	150W equivalent metabolism			250W equivalent metabolism			425W equivalent metabolism		
	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM
STDE+BA+LBE+CBD	81	69	51	45	45	30	27	28	18
Scorpion B +CBD	91	78	58	54	49	33	29	29	19
C2005+CBD	136	117	81	60	61	39	31	32	20
C2005+10cfm+CBD	>300	198	126	47	75	45	33	34	21

N/A = not available

Table 5T. Time for core temperature to reach 38.5°C under various ensembles and activities in hot temperate environment (The units are minutes.)

Non CBD Uniform	150W equivalent metabolism			250W equivalent metabolism			425W equivalent metabolism		
	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM
STDE+BA+LBE	>300	>360	>360	70	124	57	36	41	23
Scorpion A	>300	>360	>360	78	182	63	38	45	25
Scorpion B	N/A	N/A	>360	N/A	N/A	53	N/A	N/A	24
C2005	>300	>360	>360	82	260	70	38	48	26
C2005+10cfm	>300	>360	>360	108	>360	184	40	53	29

CBD Uniform	150W equivalent metabolism			250W equivalent metabolism			425W equivalent metabolism		
	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM
STDE+BA+LBE+CBD	97	92	63	48	54	34	29	30	19
Scorpion B +CBD	146	117	85	54	63	40	31	33	21
C2005+CBD	>300	>360	>360	70	112	57	35	40	24
C2005+10cfm+CBD	>300	>360	>360	96	>360	105	40	51	28

N/A = not available

Table 6D. Time for core temperature to reach 39.0°C under various ensembles and activities in hot desert environment (The units are minutes.)

Non CBD Uniform	150W equivalent metabolism			250W equivalent metabolism			425W equivalent metabolism		
	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM
STDE+BA+LBE	300	138	122	74	72	54	40	37	28
Scorpion A	300	152	124	78	78	54	42	49	28
Scorpion B	N/A	N/A	104	N/A	N/A	52	N/A	N/A	28
C2005	300	292	284	95	100	67	44	45	28
C2005+10cfm	300	360	>360	130	140	112	47	48	36

CBD Uniform	150W equivalent metabolism			250W equivalent metabolism			425W equivalent metabolism		
	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM
STDE+BA+LBE+CBD	106	67	56	55	47	35	32	31	22
Scorpion B +CBD	124	75	62	59	52	38	34	33	23
C2005+CBD	300	164	126	83	80	54	41	41	27
C2005+10cfm+CBD	300	360	>360	114	128	76	46	49	31

N/A = not available

Table 6J.   Time for core temperature to reach 39.0°C under various ensembles and activities in hot jungle environment (The units are minutes.)

Non CBD Uniform	150W equivalent metabolism			250W equivalent metabolism			425W equivalent metabolism		
	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM
STDE+BA+LBE	>300	158	125	80	76	50	40	37	26
Scorpion A	>300	185	122	87	83	52	42	39	27
Scorpion B	N/A	N/A	108	N/A	N/A	50	N/A	N/A	26
C2005	>300	222	144	92	90	56	42	42	27
C2005+10cfm	>300	360	>360	109	105	68	44	43	30

CBD Uniform	150W equivalent metabolism			250W equivalent metabolism			425W equivalent metabolism		
	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM
STDE+BA+LBE+CBD	>300	85	68	63	55	40	35	34	23
Scorpion B +CBD	>300	98	78	67	60	43	37	35	25
C2005+CBD	>300	155	116	83	77	52	41	39	27
C2005+10cfm+CBD	>300	348	242	104	99	63	44	43	29

N/A = not available

Table 6T. Time for core temperature to reach 39.0°C under various ensembles and activities in hot temperate environment (The units are minutes.)

Non CBD Uniform	150W equivalent metabolism			250W equivalent metabolism			425W equivalent metabolism		
	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM
STDE+BA+LBE	>300	360	>360	>300	180	84	49	52	32
Scorpion A	>300	360	>360	>300	360	98	53	59	34
Scorpion B	N/A	N/A	>360	N/A	N/A	81	N/A	N/A	32
C2005	>300	360	>360	>300	360	108	54	64	35
C2005+10cfm	>300	360	>360	>300	360	>360	59	72	43

CBD Uniform	150W equivalent metabolism			250W equivalent metabolism			425W equivalent metabolism		
	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM
STDE+BA+LBE+CBD	>300	115	86	70	66	45	37	36	24
Scorpion B +CBD	>300	150	120	84	79	54	40	41	28
C2005+CBD	>300	360	>360	244	152	82	48	52	31
C2005+10cfm+CBD	>300	360	>360	>300	360	223	57	68	40

N/A = not available

Table 7D.   Time for core temperature to reach 39.5°C under various ensembles and activities in hot desert environment (The units are minutes.)

Non CBD Uniform	150W equivalent metabolism			250W equivalent metabolism			425W equivalent metabolism		
	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM
STDE+BA+LBE	>300	179	178	125	89	69	51	45	35
Scorpion A	>300	208	192	146	97	71	54	48	35
Scorpion B	N/A	N/A	146	N/A	N/A	66	N/A	N/A	35
C2005	>300	>360	>360	>300	129	91	59	53	35
C2005+10cfm	>300	>360	>360	>300	202	>360	63	58	48

CBD Uniform	150W equivalent metabolism			250W equivalent metabolism			425W equivalent metabolism		
	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM
STDE+BA+LBE+CBD	>300	80	68	73	56	43	40	36	27
Scorpion B +CBD	>300	90	77	81	61	47	43	38	28
C2005+CBD	>300	217	182	204	98	69	54	48	34
C2005+10cfm+CBD	>300	>360	>360	>300	174	109	64	59	40

N/A = not available

Table 7J. Time for core temperature to reach 39.5°C under various ensembles and activities in hot jungle environment (The units are minutes.)

Non CBD	150W equivalent metabolism				250W equivalent metabolism				425W equivalent metabolism		
Uniform	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM
STDE+BA+LBE	300	214	182	175	94	65	51	46	32
Scorpion A	300	271	186	>300	105	68	55	49	33
Scorpion B	N/A	N/A	151	N/A	N/A	64	N/A	N/A	33
C2005	300	352	224	>300	115	72	55	51	34
C2005+10cfm	300	360	>360	>300	138	93	58	53	38

CBD	150W equivalent metabolism				250W equivalent metabolism				425W equivalent metabolism		
Uniform	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM	HSDA	SCENARIO_J	Simulink2NM
STDE+BA+LBE+CBD	>300	103	84	90	65	49	43	40	29
Scorpion B +CBD	>300	120	99	102	72	54	47	41	30
C2005+CBD	>300	203	159	234	94	67	52	57	33
C2005+10cfm+CBD	>300	360	>360	>300	127	85	58	52	37

N/A = not available

Table 7T. Time for core temperature to reach 39.5°C under various ensembles and activities in hot temperate environment (The units are minutes.)

Non CBD	150W equivalent metabolism			250W equivalent metabolism			425W equivalent metabolism		
Uniform	HSDA	SCENARIO J	Simulink2NM	HSDA	SCENARIO J	Simulink2NM	HSDA	SCENARIO J	Simulink2NM
STDE+BA+LBE	>300	>360	>360	>300	273	116	67	64	41
Scorpion A	>300	>360	>360	>300	>360	146	76	75	44
Scorpion B	N/A	N/A	>360	N/A	N/A	111	N/A	N/A	41
C2005	>300	>360	>360	>300	>360	164	78	81	45
C2005+10cfm	>300	>360	>360	>300	>360	>360	89	94	50

CBD	150W equivalent metabolism			250W equivalent metabolism			425W equivalent metabolism		
Uniform	HSDA	SCENARIO J	Simulink2NM	HSDA	SCENARIO J	Simulink2NM	HSDA	SCENARIO J	Simulink2NM
STDE+BA+LBE+CBD	>300	139	107	112	78	56	47	43	30
Scorpion B +CBD	>300	188	160	273	95	68	52	48	34
C2005+CBD	>300	>360	>360	>300	203	111	66	62	41
C2005+10cfm+CBD	>300	>360	>360	>300	>360	>360	86	88	54

NA = not available

CORE TEMPERATURES AND NON-CDB EQUIPPED CLOTHING

The benefits of the prototype uniform systems can be better seen and appreciated from the graphs of Tcr responses as predicted by the three different simulation methods for the various uniforms and conditions. Figure 4Da gives the simulated responses for desert conditions with non-CBD clothing systems at 150W equivalent activities. The performance differences that result from each design are clearly evident. All three different simulation techniques give similar responses.

Figure 4Da. Core temperature simulated responses by HSDA, SCENARIO_J and Simulink2NM for150W nominal activities in non-CBD clothing in a desert summer environment

NonCBD clothing comparison by HSDA for 150W activity in Desert

NonCBD clothing comparison by SCENARIO_J for 150W activity in Desert

NonCBD clothing comparison by Simulink2NM for 150W activity in Desert
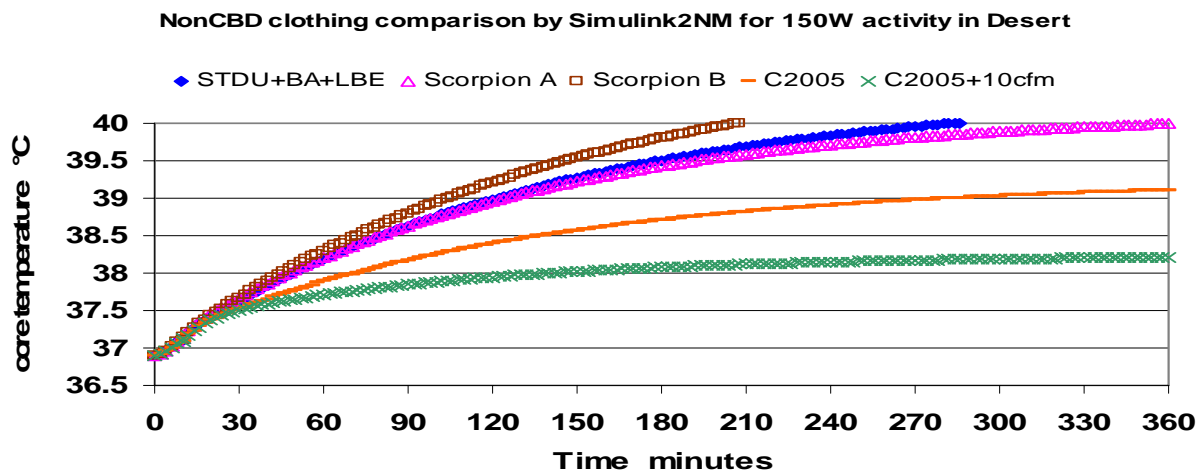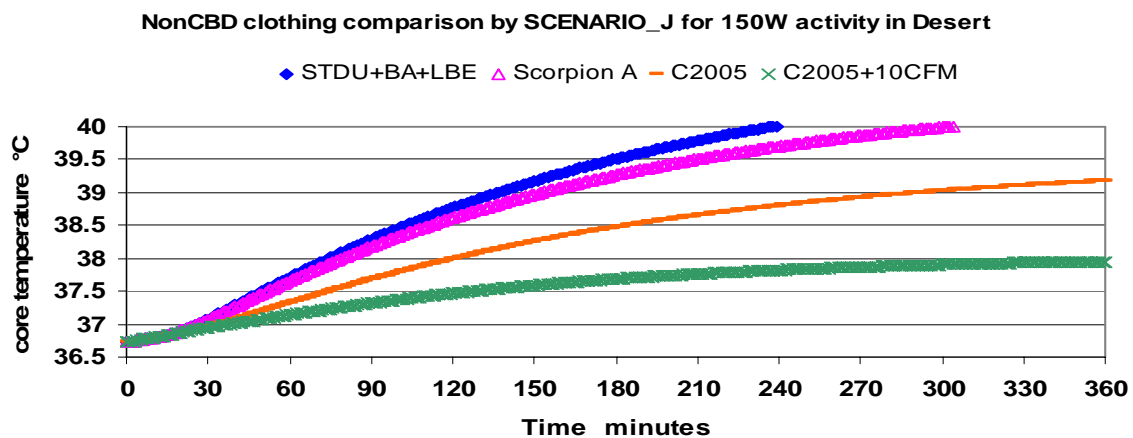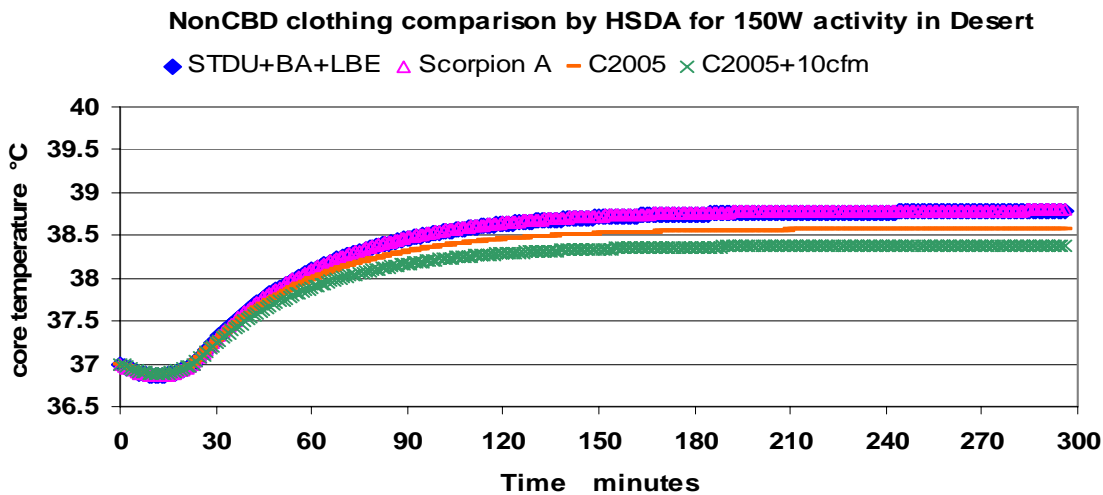
The simulated responses for desert conditions with non-CBD clothing systems at 250W equivalent activities are shown in Figure 4Db and the responses for 425W equivalent activities are in Figure 4Dc. It is seen that the clothing design benefit of cooler core temperatures are more pronounced at lower activities.

Figure 4Db. Core temperature simulated responses by HSDA, SCENARIO_J and Simulink2NM for 250W nominal activities in non-CBD clothing in a desert summer environment

NonCBD clothing comparison by HSDA for 250W activity in Desert

◇ STDU+BA+LBE △ Scorpion A ─ C2005 ✕ C2005+10CFM

NonCBD clothing comparison by SCENARIO_J for 250W activity in Desert

◆ STDU+BA+LBE △ Scorpion A ─ C2005 ✕ C2005+10CFM

NonCBD Clothing comparison by Simulink2NM for 250W activity in Desert

◆ STDU+BA+LBE ◇ Scorpion A □ Scorpion B ─ C2005 ✕ C2005+10cfm
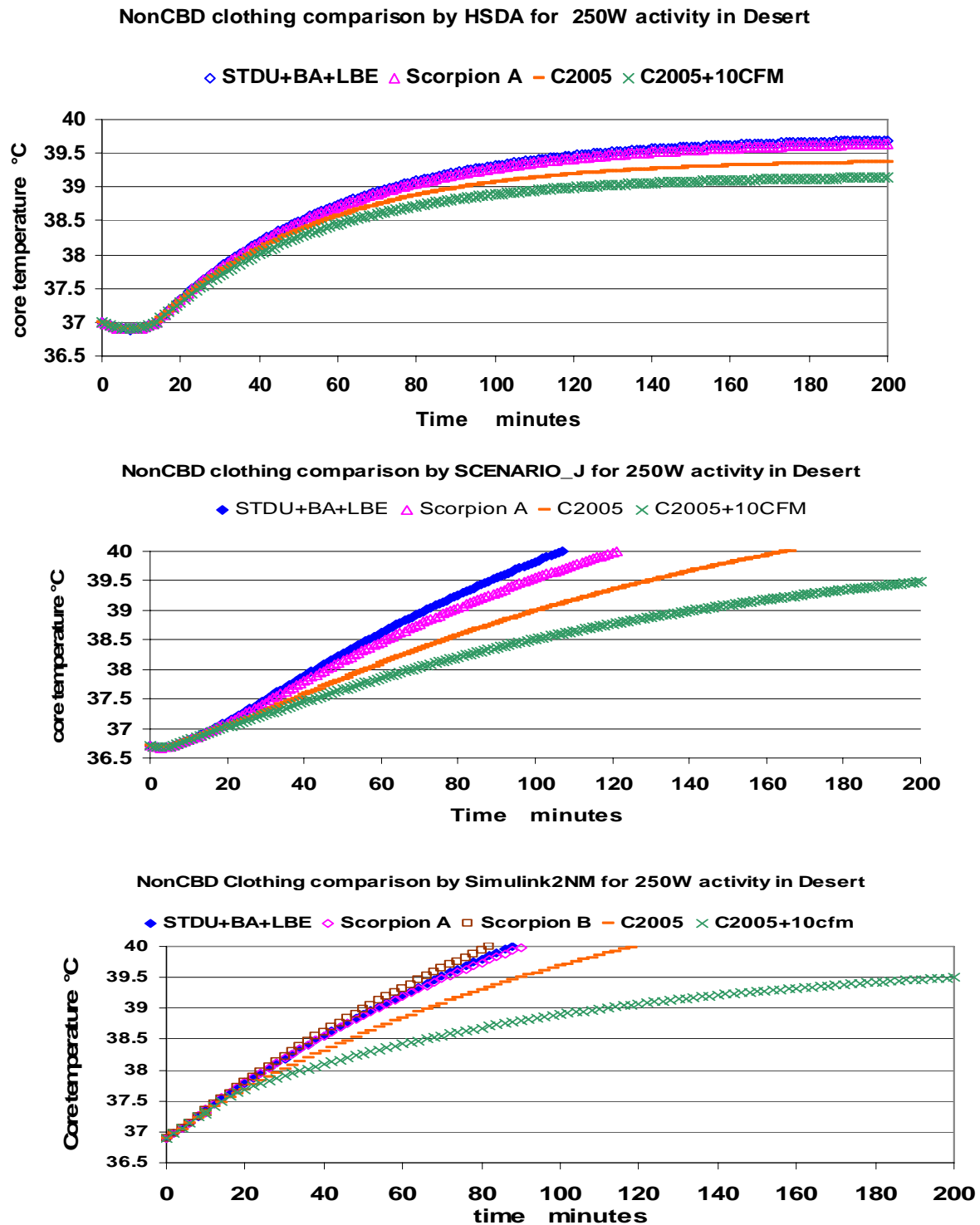
Figure 4Dc. Core temperature simulated responses by HSDA, SCENARIO_J and Simulink2NM for 425W nominal activities in non-CBD clothing in a desert summer environment

NonCBD clothing comparison by HSDA for 425W activity in Desert

◆ STDU+BA+LBE △ Scorpion A — C2005 ✕ C2005+10CFM

NonCBD clothing comparison by SCENARIO_J for 425W activity in Desert

◆ STDU+BA+LBE △ Scorpion A — C2005 ✕ C2005+10CFM

nonCBD Clothing comparison by Simulink2NM for 425W activity in Desert

◆ STDU+BA+LBE △ Scorpion A ☐ Scorpion B — C2005 ✕ C2005+10cfm

The simulated Soldier responses for jungle conditions wearing the clothing systems and engaged in equivalent activities of 150, 250 and 425W are given in Figures 4Ja, 4Jb, and 4Jc. The jungle conditions are cooler but the humidity is much higher than the desert (Table 4). The effect of the clothing design on Tcr is much less at the higher activity levels, particularly as simulated by HSDA.

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Figure 4Ja. Core temperature simulated responses by HSDA, SCENARIO_J and Simulink2NM for 150W nominal activities in non-CBD clothing in a jungle summer environment

nonCBD clothing comparison by HSDA for 150W activity in Jungle

◆ STDU+BA+LBE △ Scorpion A — C2005 × C2005+10CFM

NonCBD clothing comparison by SCENARIO_J for 150W activity in Jungle

◆ STDU+BA+LBE △ Scorpion A — C2005 × C2005+10CFM

NonCBD clothing comparison by Simulink2NM for 150W activity in Jungle

◆ STDU+BA+LBE △ Scorpion A □ Scorpion B — C2005 × C2005+10cfm

Figure 4Jb. Core temperature simulated responses by HSDA, SCENARIO_J and Simulink2NM for 250W nominal activities in non-CBD clothing in a jungle summer environment

NonCBD clothing comparison by HSDA for 250W activity in Jungle

◆ STDU+BA+LBE   △ Scorpion A   — C2005   ✕ C2005+10CFM

NonCBD clothing comparison by SCENARIO_J for 250W activity in Jungle

◆ STDU+BA+LBE   △ Scorpion A   — C2005   ✕ C2005+10CFM

NonCBD clothing comparison by Simulink2NM for 250W activity in Jungle

◆ STDU+BA+LBE   △ Scorpion A   □ Scorpion B   — C2005   ✕ C2005+10cfm

Figure 4Jc. Core temperature simulated responses by HSDA, SCENARIO_J and Simulink2NM for 425W nominal activities in non-CBD clothing in a jungle summer environment

NonCBD clothing comparison by HSDA for 425W activity in Jungle

NonCBD clothing comparison by SCENARIO_J for 425W activity in Jungle

The simulated responses for temperate conditions with the clothing systems engaged in 150, 250 and 425W equivalent activities are given in Figures 4Ta, 4Tb, and 4Tc. The temperate conditions have the same temperature at lower humidity than the jungle (Table 4). It seems that benefits of the new clothing designs in terms of Tcr are similar to the predictions for the desert (Figure 4Da, b, c).

Figure 4Ta. Core temperature simulated responses by HSDA, SCENARIO_J and Simulink2NM for 150W nominal activities in non-CBD clothing in a temperate summer environment

NonCBD clothing comparison by HSDA for 150W activity in Temperate

◆ STDU+BA+LBE △ Scorpion A ▬ C2005 ✕ C2005+10CFM

NonCDB clothing comparison by SCENARIO_J for 150W activity in Temperate

◆ STDU+BA+LBE △ Scorpion A ▬ C2005 ✕ C05+10CFM

NonCBD clothing comparison by Simulink2NM for 150W activity in Temperate

◆ STDU+BA+LBE ▢ Scorpion B ▬ C2005 ✕ C2005+10cfm

Figure 4Tb. Core temperature simulated responses by HSDA, SCENARIO_J and Simulink2NM for 250W nominal activities in non-CBD clothing in a temperate summer environment

NonCBD clothing comparison by HSDA for 250W activity in Temperate

NonCBD clothing comparison by SCENARIO_J for 250W activity in Temperate

NonCBD clothing comparison by Simulink2NM for 250W activity in Temperate

Figure 4Tc. Core temperature simulated responses by HSDA, SCENARIO_J and Simulink2NM for 425W nominal activities in non-CBD clothing in a temperate summer environment

NonCBD clothing comparison by HSDA for 425W activity in Temperate

♦ STDU+BA+LBE △ Scorpion A — C2005 ✕ C2005+10CFM

NonCBD clothing comparison by SCENARIO_J for 425W activity inTemperate

♦ STDU+BA+LBE △ Scorpion A — C2005 ✕ C2005+10CFM

NonCBD clothing comparison by Simulink2NM for 425W activity in Temperate

♦ STDU+BA+LBE △ Scorpion A □ Scorpion B — C2005 ✕ C2005+10cfm

CORE TEMPERATURES AND CBD EQUIPPED CLOTHING

The simulated Soldier Tcr response comparisons for the clothing systems with CBD gear are presented in Figures 5D, J and T. Figures 5Da, 5Db, and 5Dc give the simulated responses for desert conditions with the clothing systems equipped for CBD and equivalent activities of 150, 250 and 425W. The benefits of lowering Tcr between the different clothing systems are substantial when Soldiers are equipped for CBD. The benefits continue even at high activity levels.

Figure 5Da. Core temperature simulated responses by HSDA, SCENARIO_J and Simulink2NM for 150W nominal activities in CBD clothing in a desert summer environment

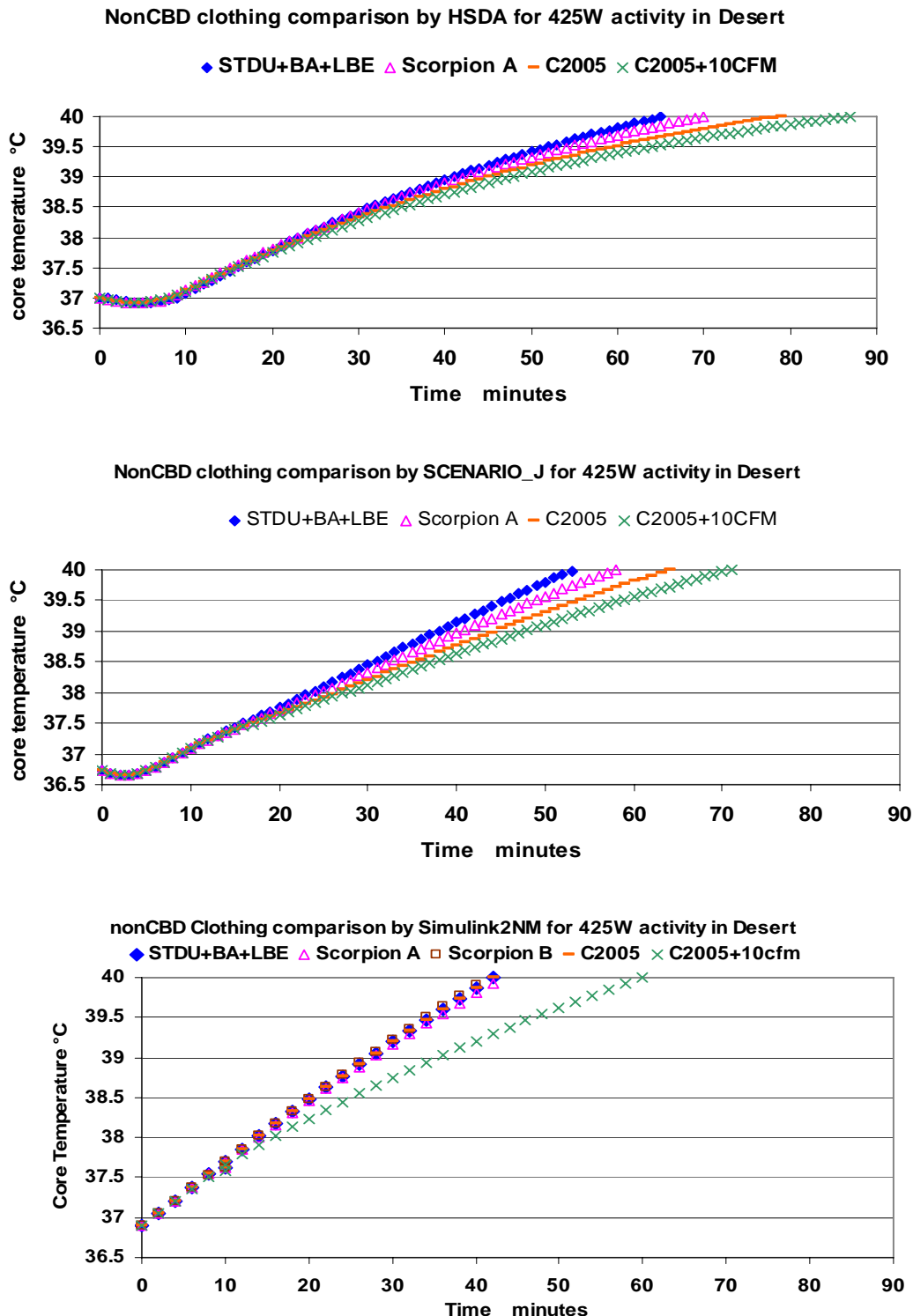CBD clothing comparison by HSDA for 150W activity in Desert

CBD clothing comparison by SCENARIO_J for 150W activity in Desert

CBD clothing comparison by Simulink2NM for 150W activity in Desert

Figure 5Db. Core temperature simulated responses by HSDA, SCENARIO_J and Simulink2NM for 250W nominal activities in CBD clothing in a desert summer environment

CBD clothing comparison by HSDA for 250W activity in Desert

STDU+BA+LBE+CBD   Scorpion B+CBD   C2005+CBD   C2005+10CFM+CBD

CBD clothing comparison by SCENARIO_J for 250W activity in Desert

STDU+BA+LBE+CBD   Scorpion B+CBD   C2005+CBD   C2005+10CFM+CBD

CBD clothing comparison by Simulink2NM for 250W activity in Desert

STDU+BA+LBE+CBD   Scorpion B+CBD   C2005+CBD   C2005+10CFM+CBD
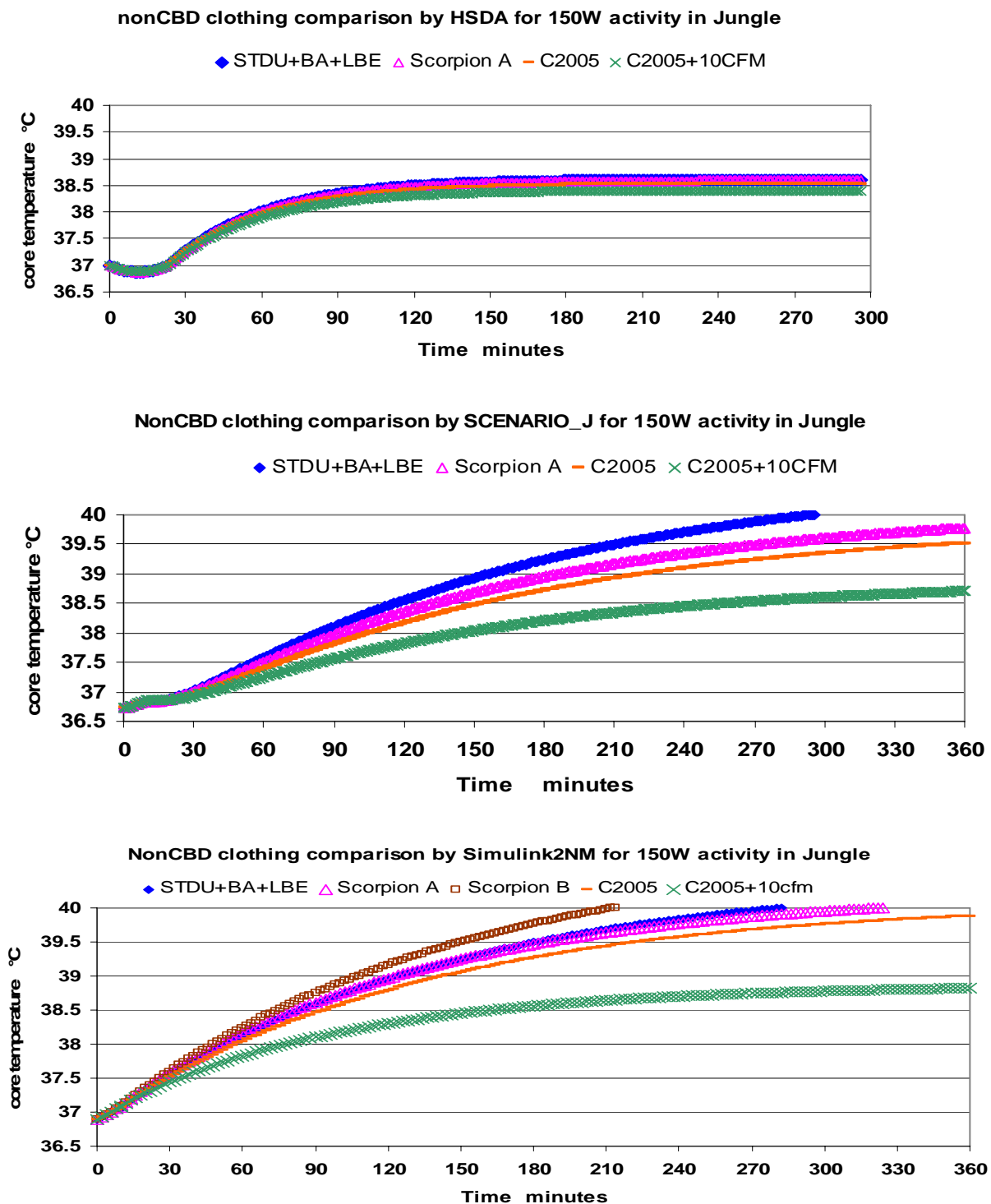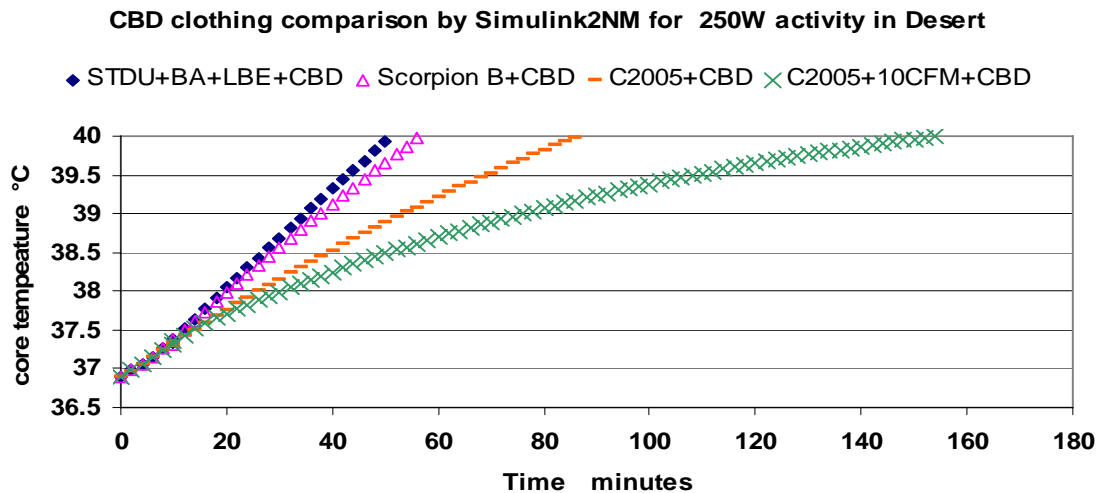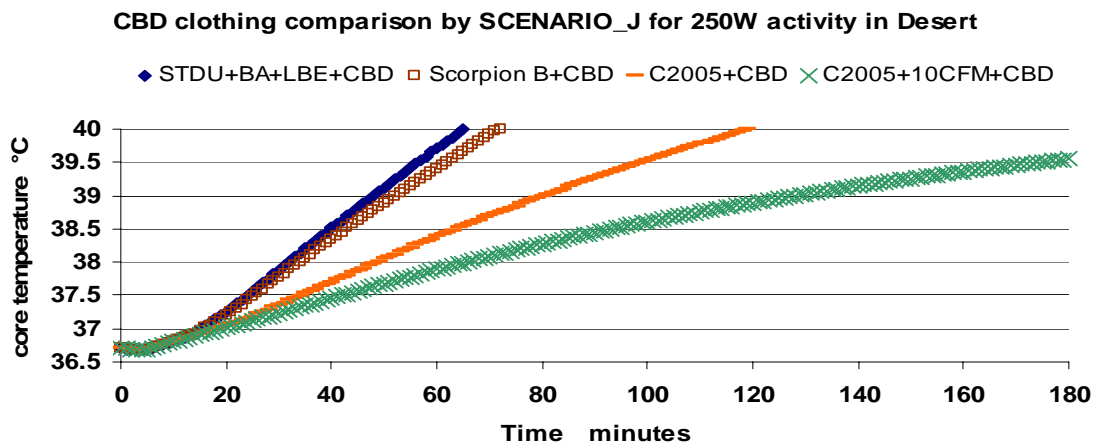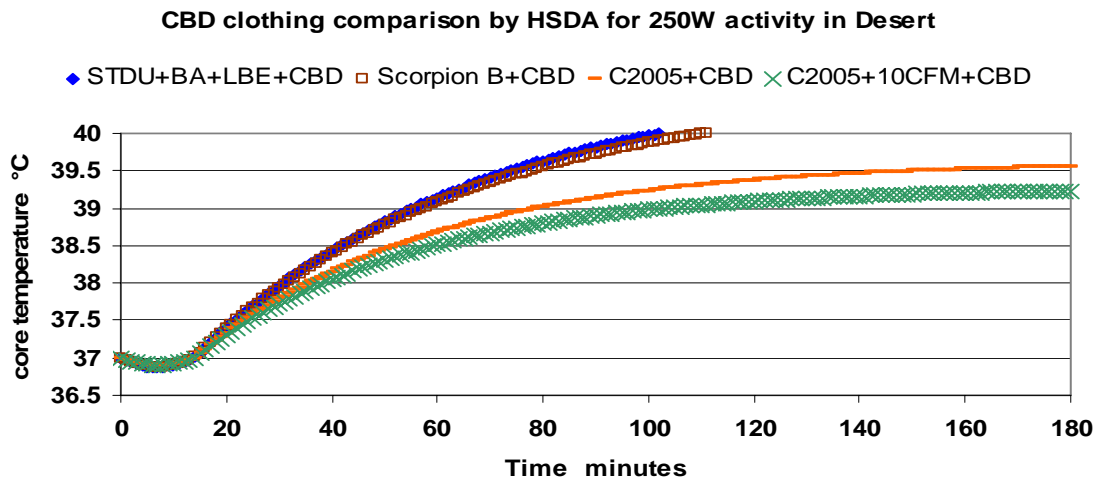
Figure 5Dc. Core temperature simulated responses by HSDA, SCENARIO_J and Simulink2NM for 425W nominal activities in CBD clothing in a desert summer environment

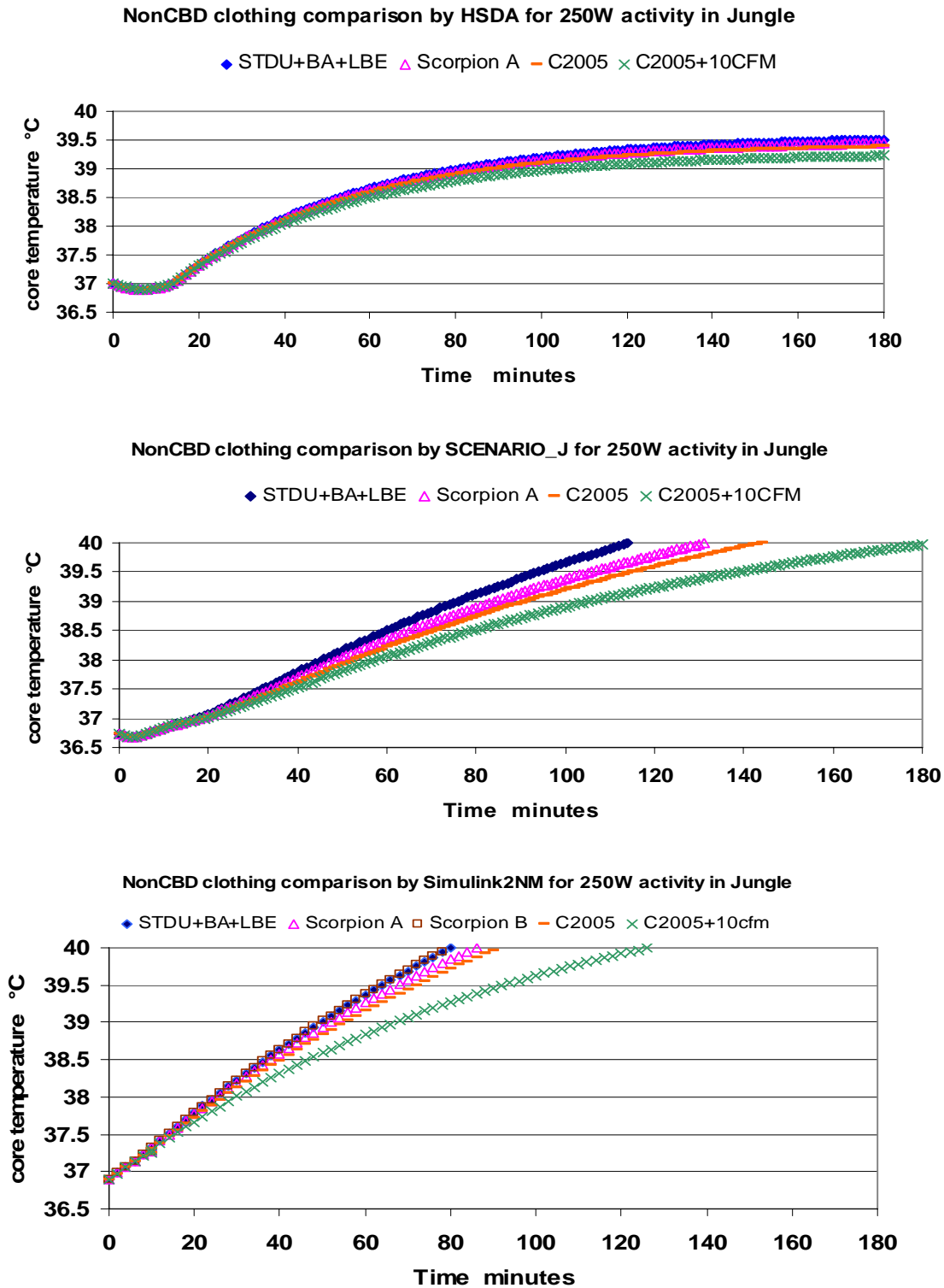**CBD clothing comparison by HSDA for 425W activity in Desert**

◆ STDU+BA+LBE   □ Scorpion B+CBD   ◇ C2005+CBD   □ C2005+10CFM+CBD

CBD clothing comparison by SCENARIO_J for 425W activity in Desert

◆ STDU+BA+LBE+CBD   □ Scorpion B+CBD   — C2005+CBD   ✕ C2005+10CFM+CBD

CBD clothing comparison by Simulink2NM for 425W activity in Desert

◆ STDU+BA+LBE+CBD   □ Scorpion B+CBD   — C2005+CBD   ✕ C2005+10cfm+CBD

The simulated responses for jungle conditions with the clothing systems equipped for CBD at 150, 250 and 425W of equivalent activities are given in Figures 5Ja, 5Jb, and 5Jc. The jungle conditions are cooler but the humidity is much higher than the desert (Table 4). The Tcr response differences between the uniforms with CBD are much larger than the differences between non-CBD clothing systems in jungle (Figure 4Ja, b, c).
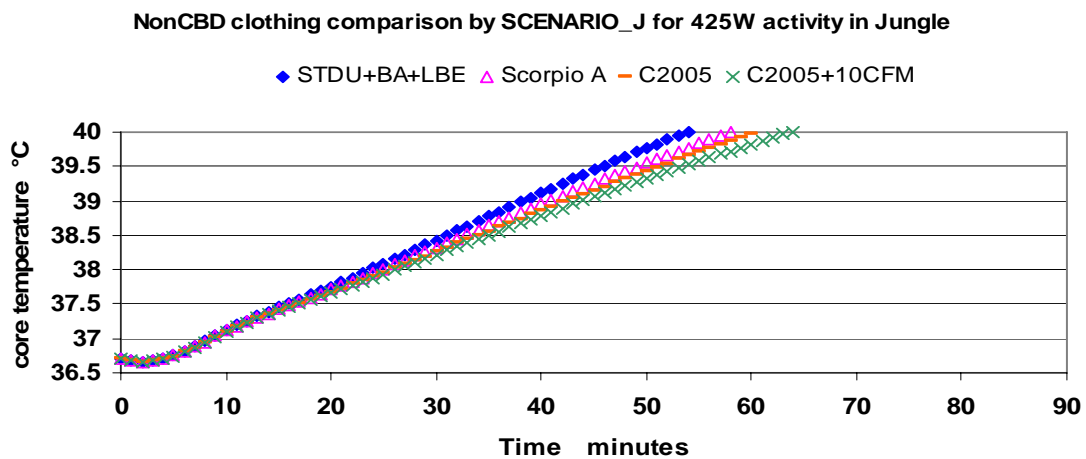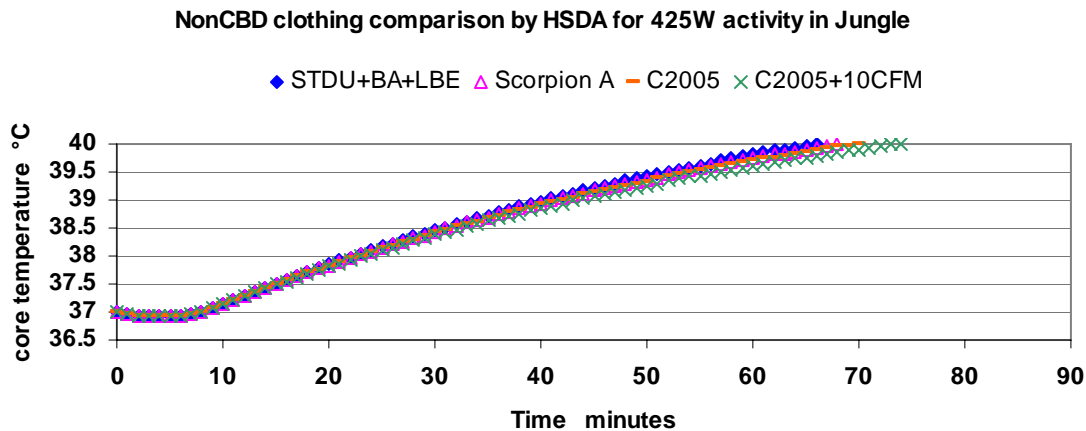
Figure 5Ja. Core temperature simulated responses by HSDA, SCENARIO_J and Simulink2NM for 150W nominal activities in CBD clothing in a jungle summer environment

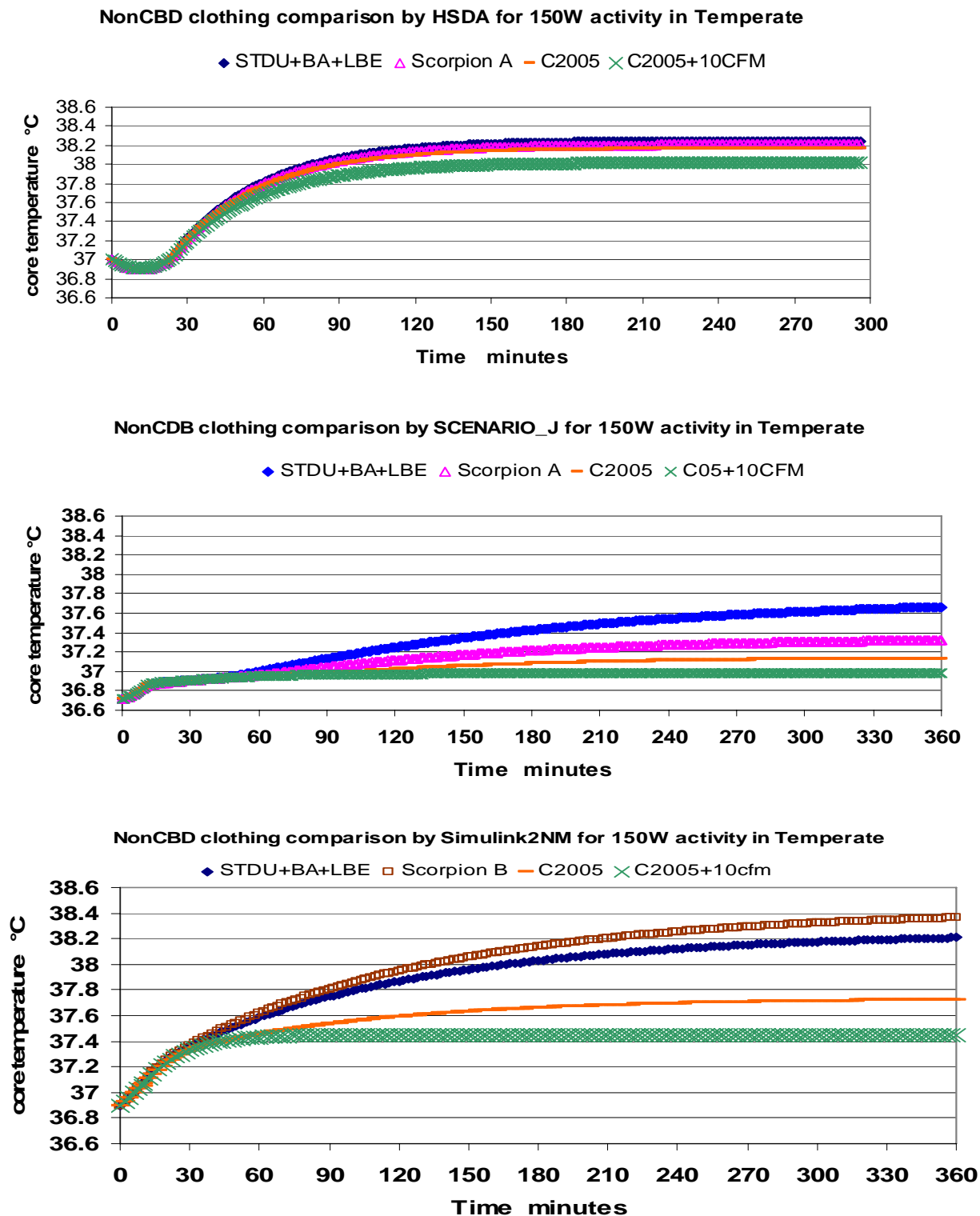### CBD clothing comparison by HSDA for 150W activity in Jungle

CBD clothing comparison by SCENARIO_J for 150W activity in Jungle

CBD clothing comparison by Simulink2NM for 150W activity in Jungle
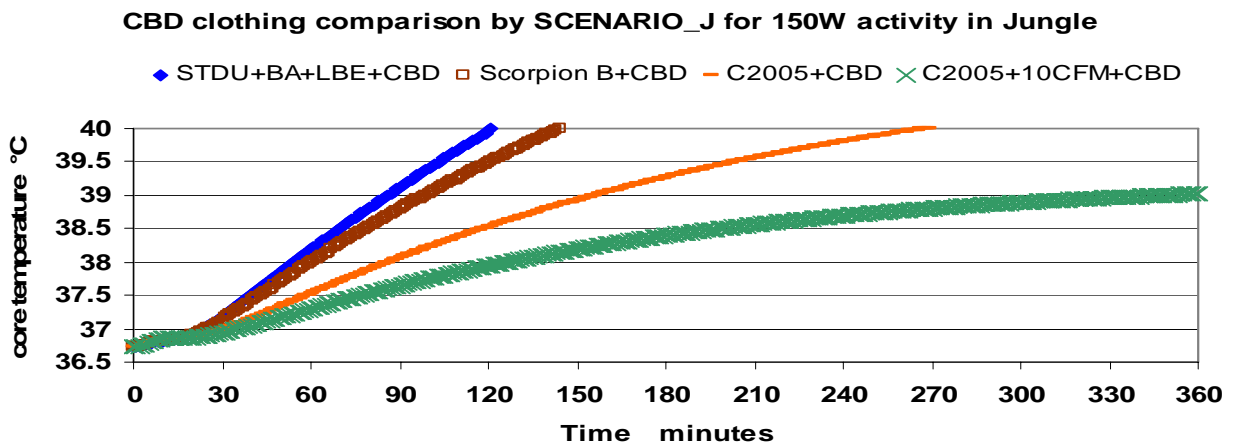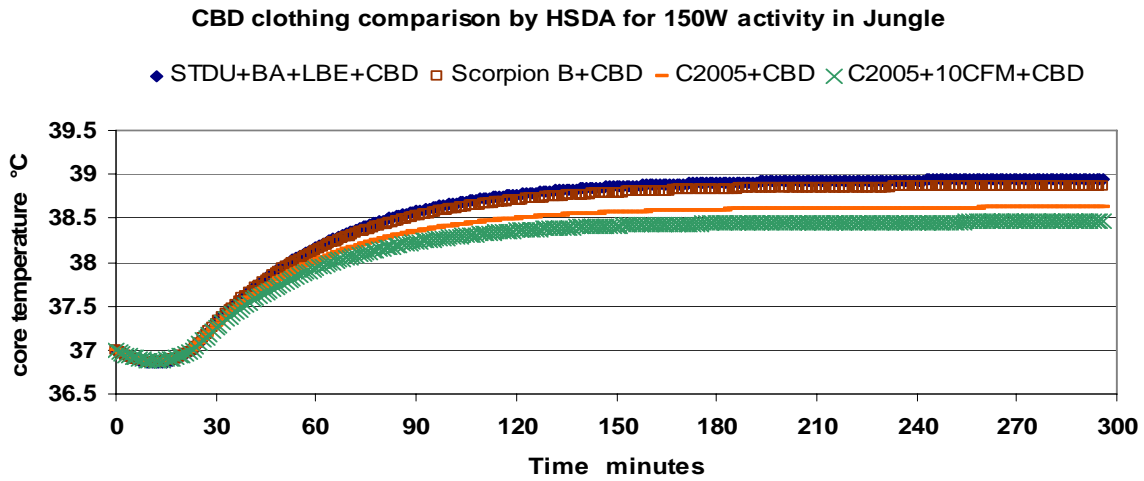
Figure 5Jb. Core temperature simulated responses by HSDA, SCENARIO_J and Simulink2NM for 250W nominal activities in CBD clothing in a jungle summer environment

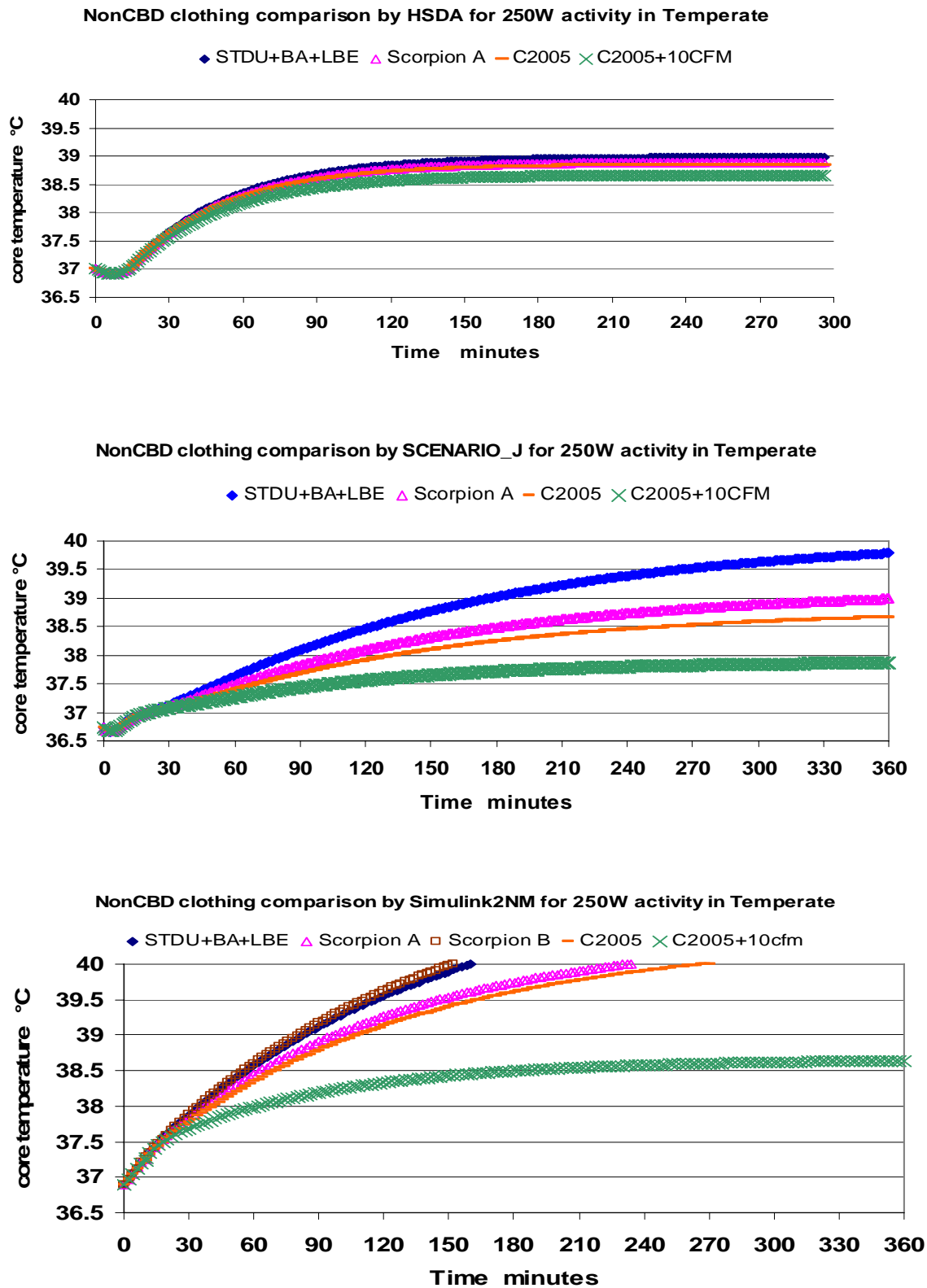CBD clothing comparison by HSDA for 250W activity in Jungle

CBD clothing comparison by SCENARIO_J for 250W activity in Jungle

CBD clothing comparison by Simulink2NM for 250W activity in Jungle
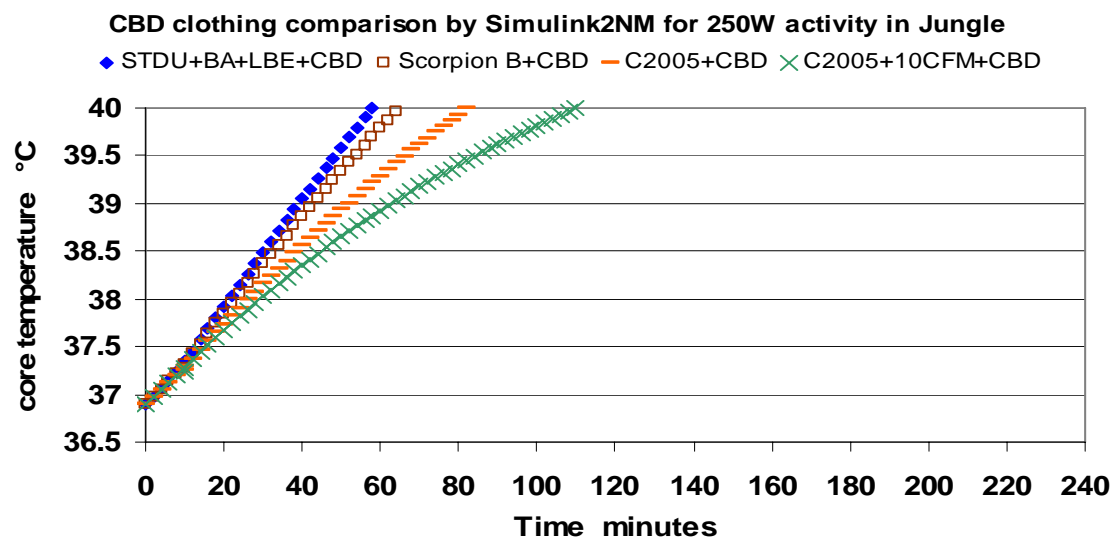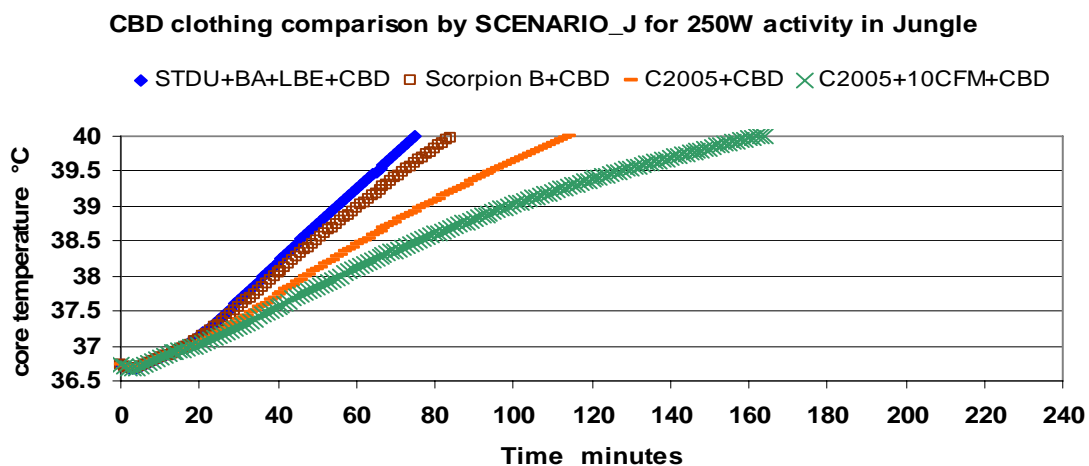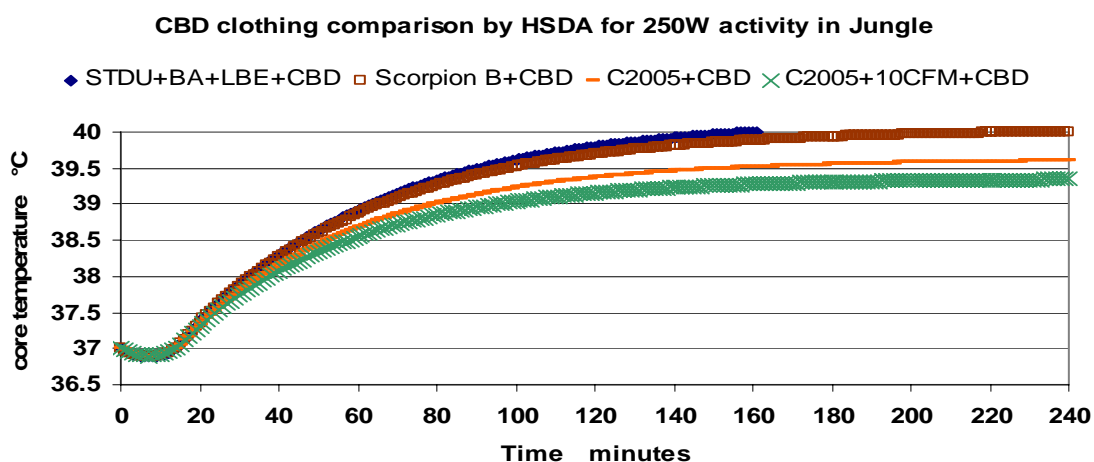
Figure 5Jc. Core temperature simulated responses by HSDA, SCENARIO_J and Simulink2NM for 425W nominal activities in CBD clothing in a jungle summer environment

CBD clothing comparison by HSDA for 425W activity in Jungle

CBD clothing comparison by SCENARIO_J for 425W activity in Jungle

CBD clothing comparison by Simlulink2NM for 425W activity in Jungle
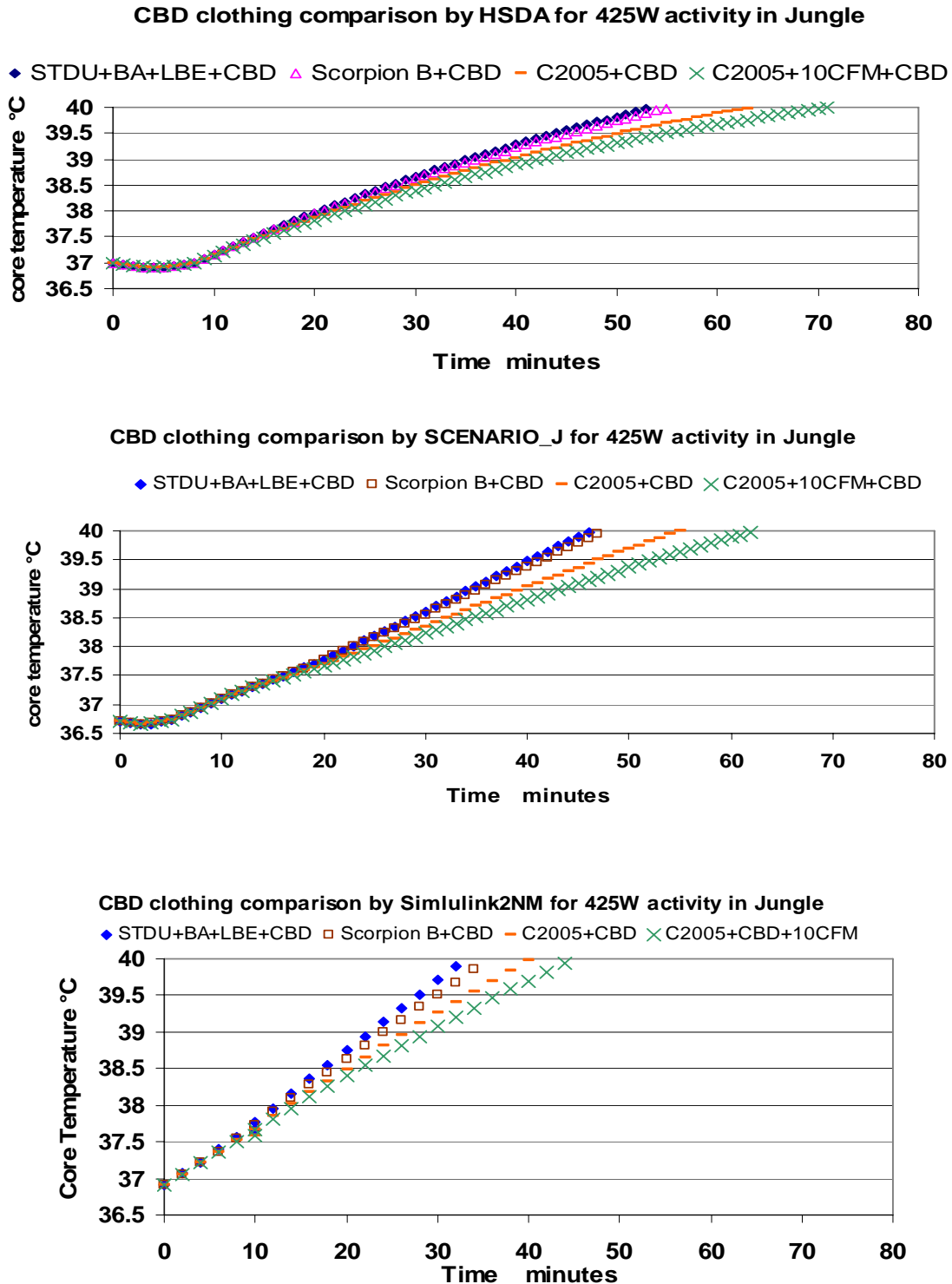
The simulated responses for temperate conditions with the clothing systems equipped for CBD at 150, 250 and 425W equivalent activities are given in Figures 5Ta, 5Tb, and 5Tc. The temperate conditions have the same temperature but a lower humidity than the jungle (Table 4). The response differences between the CBD clothing systems are substantial.
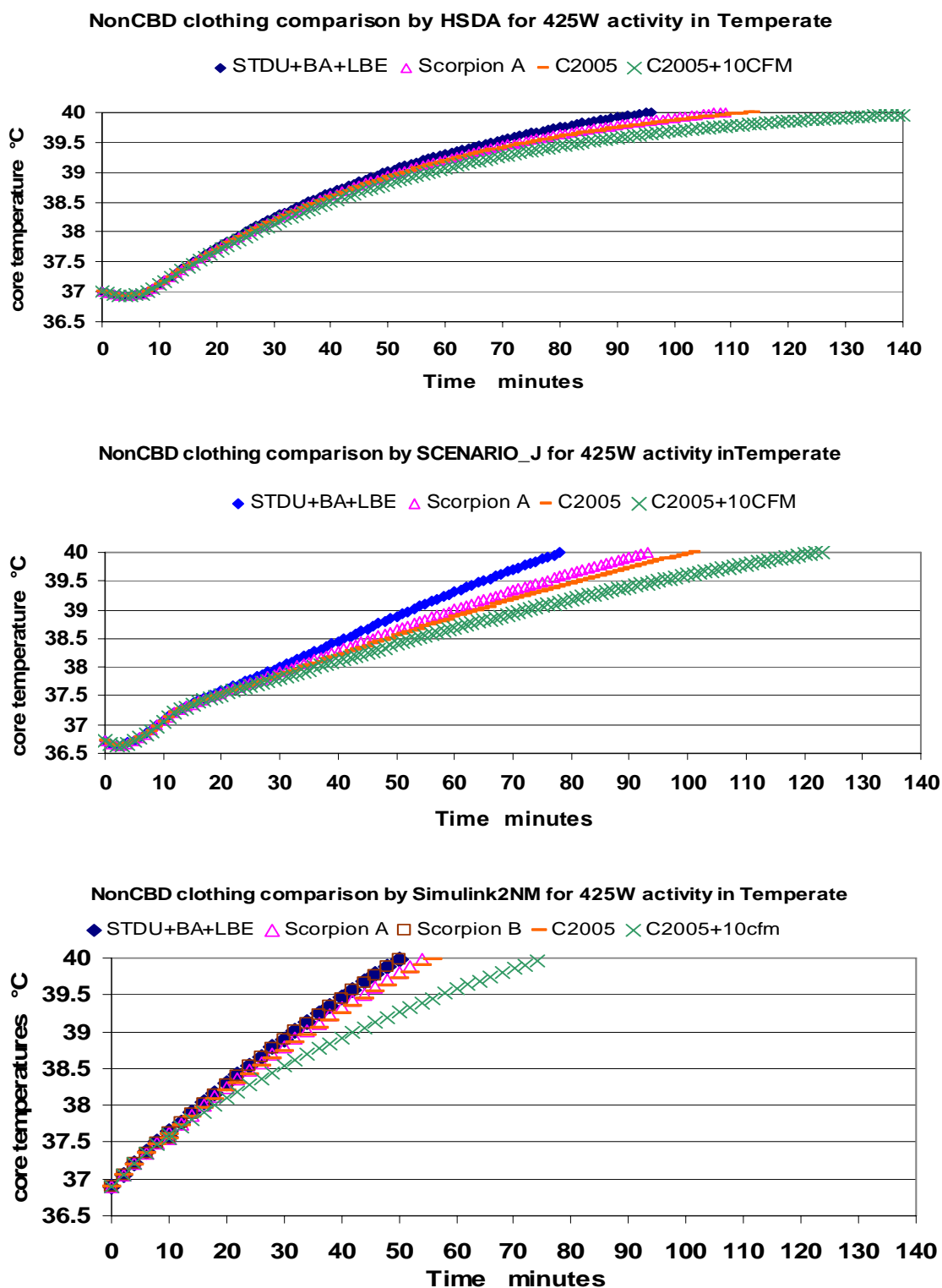
Figure 5Ta. Core temperature simulated responses by HSDA, SCENARIO_J and Simulink2NM for 150W nominal activities in CBD clothing in a temperate summer environment
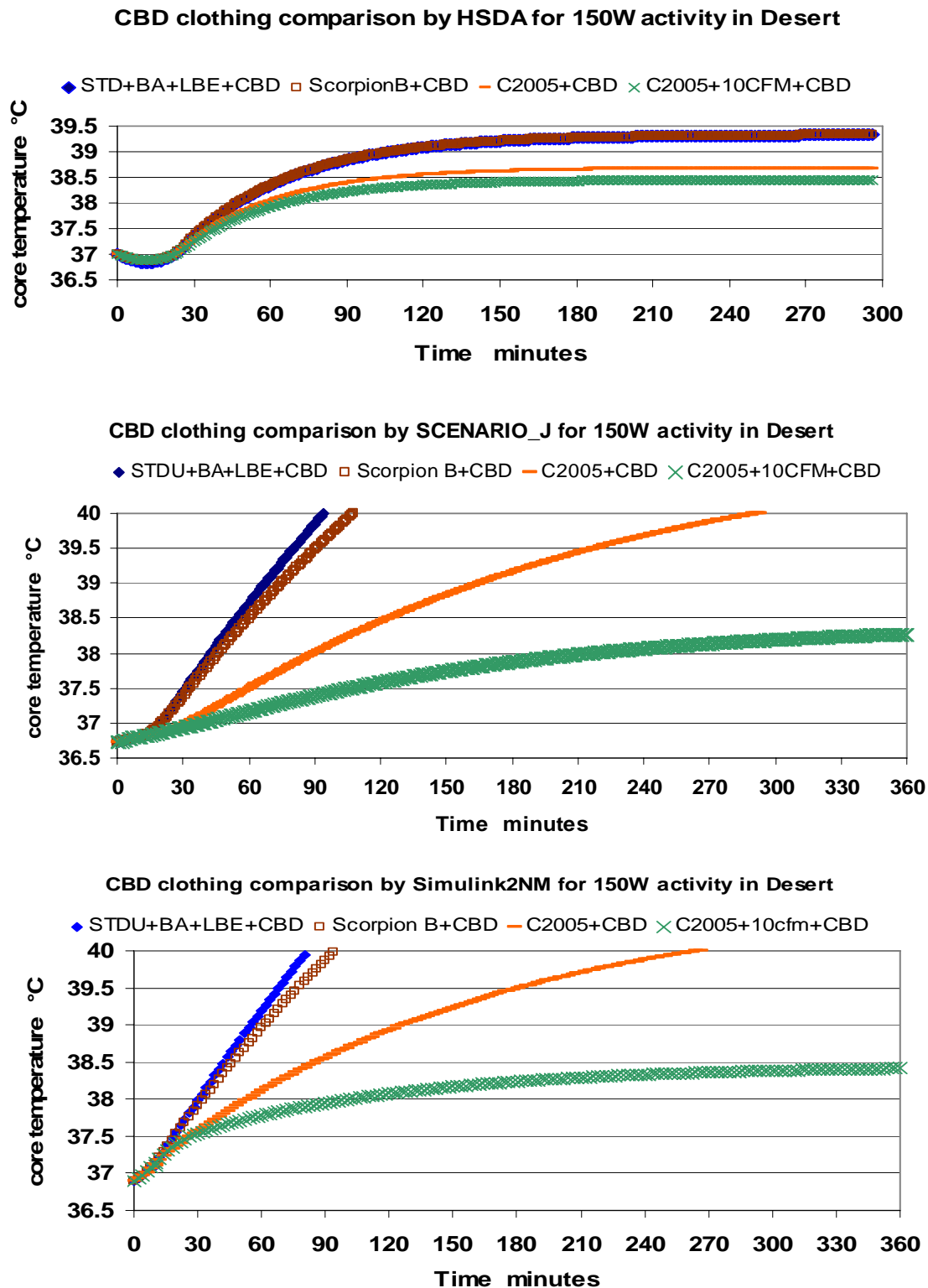
CBD clothing comparison by HSDA for 150W activity in Temperate

◆ STDU+BS+LBE+CBD □ Scorpion B+CBD — C2005+CBD ✕ C2005+10CFM+CBD

CBD clothing comparison by SCENARIO_J for 150W activity in Temperate

◆ STDU+BA+LBE+CBD □ Scorpion B+CBD — C2005+CBD ✕ C2005+10CFM+CBD

CBD clothing comparison by Simulink2NM for 150W activity in Temperate

◆ STDU+BA+LBE+CBD □ Scorpion B+CBD — C2005+CBD ✕ C2005+10cfm+CBD
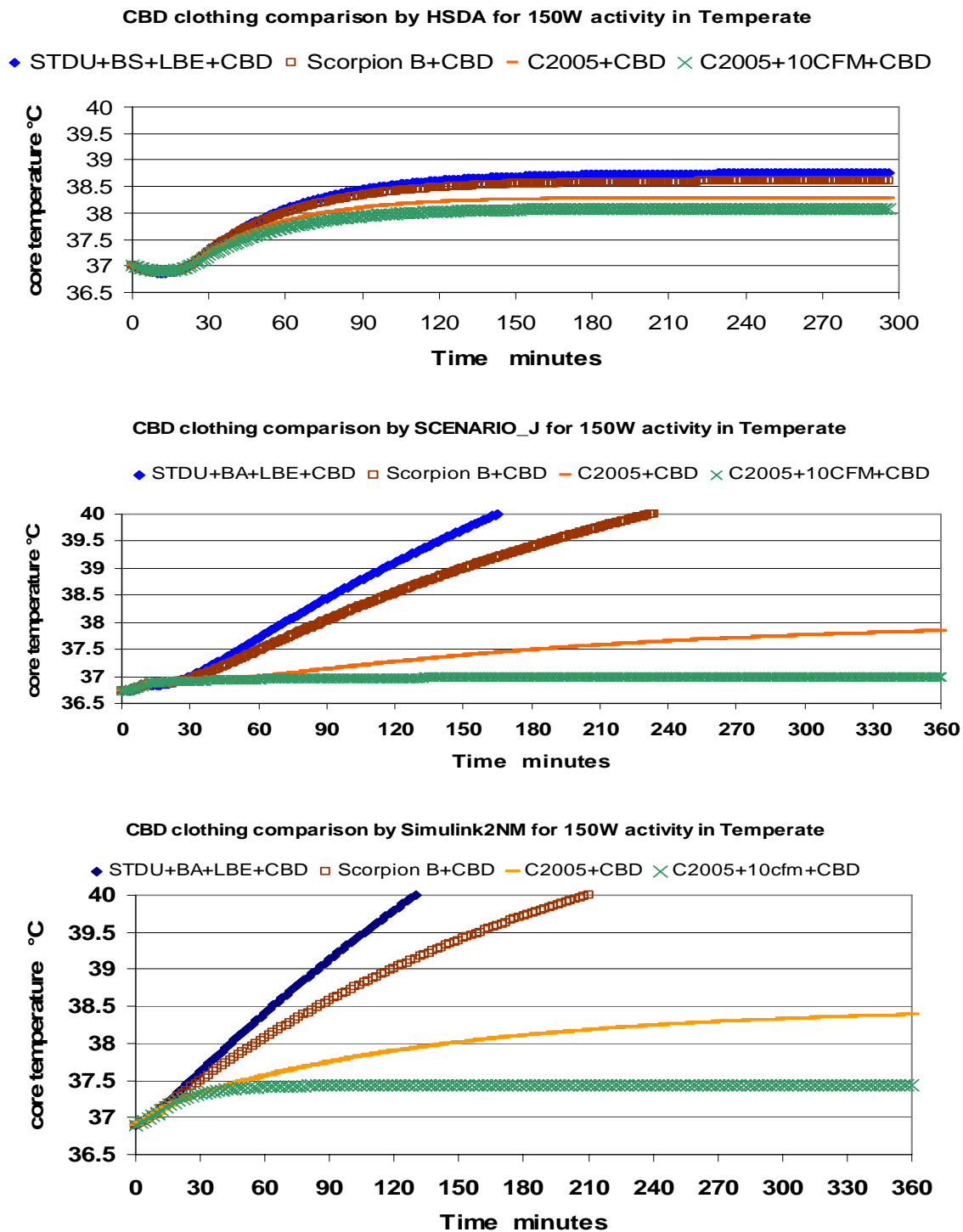
Figure 5Tb. Core temperature simulated responses by HSDA, SCENARIO_J and Simulink2NM for 250W nominal activities in CBD clothing in a temperate summer environment

CBD clothing comparison by HSDA for 250W activity in Temperate

◆ STDU+BA+LBE+CBD □ ScorpionB+CBD — C2005+CBD ✕ C2005+10CFM+CBD

CBD clothing comparison by SCENARIO_J for 250W activity inTemperate

◆ STDU+BA+LBE+CBD □ Scorpion B — C2005+CBD ✕ C2005+10CFM+CBD

CBD clothing comparison by Simulink2NM for 250W activity in Temperate

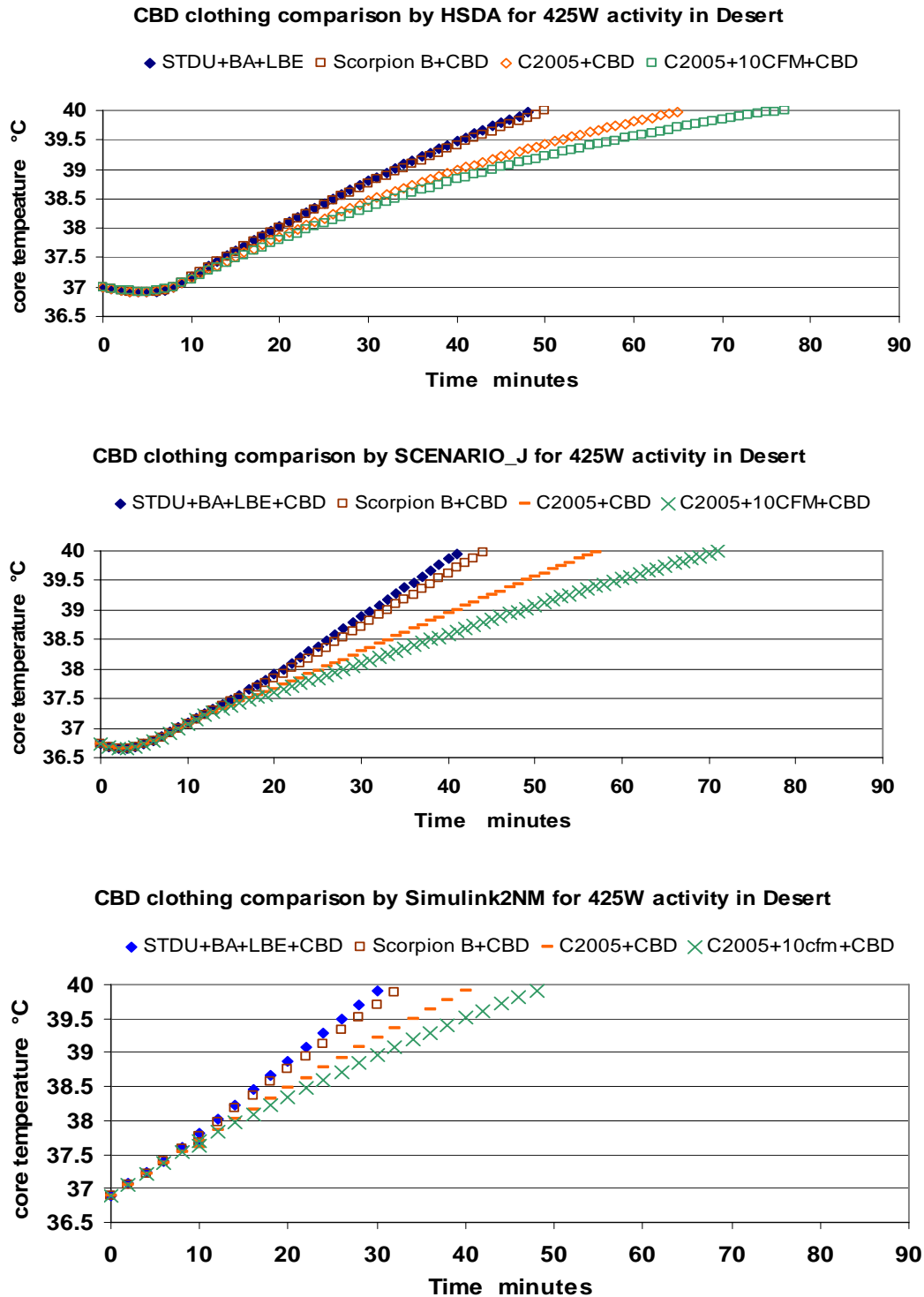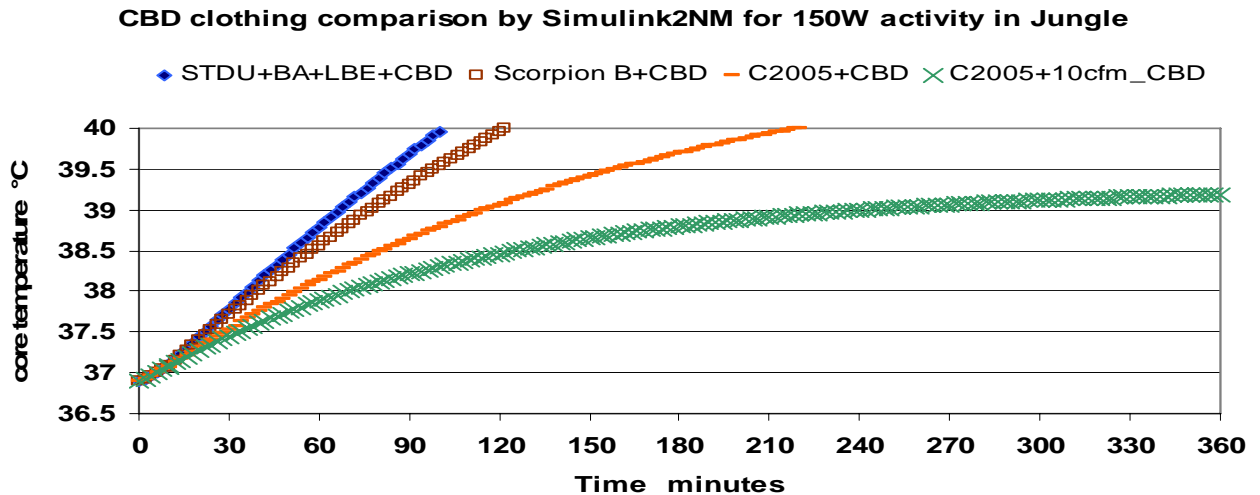◆ STDU+BA+LBE+CBD □ Scorpion B+CBD — C2005+CBD ✕ C2005+10cfm+CBD
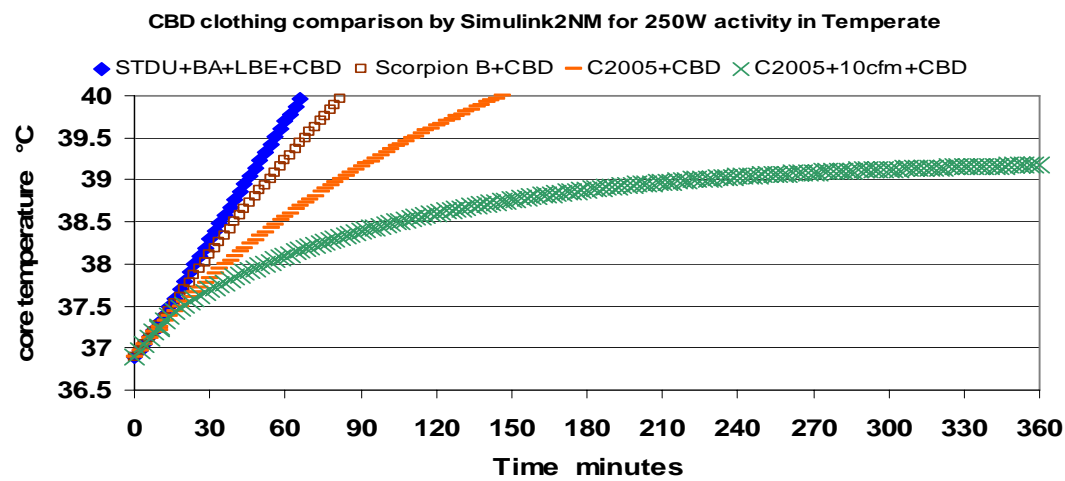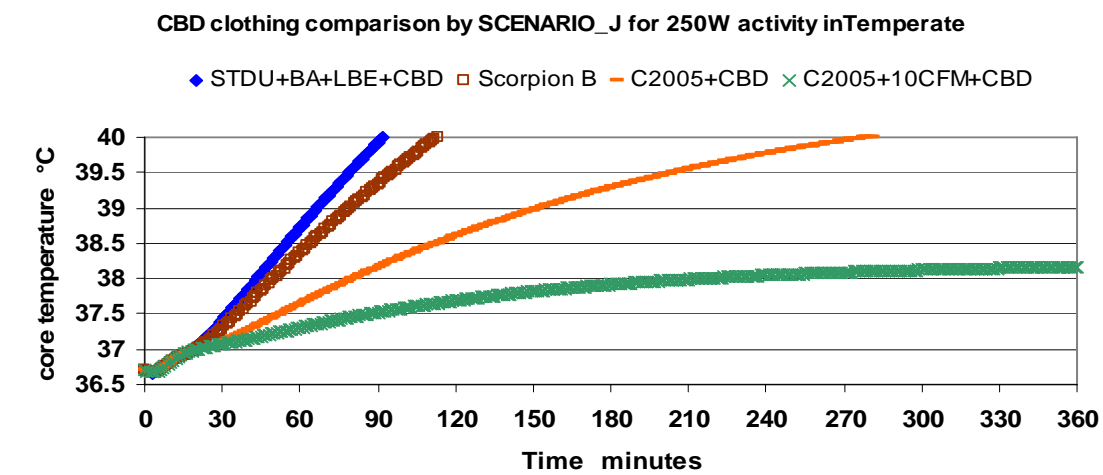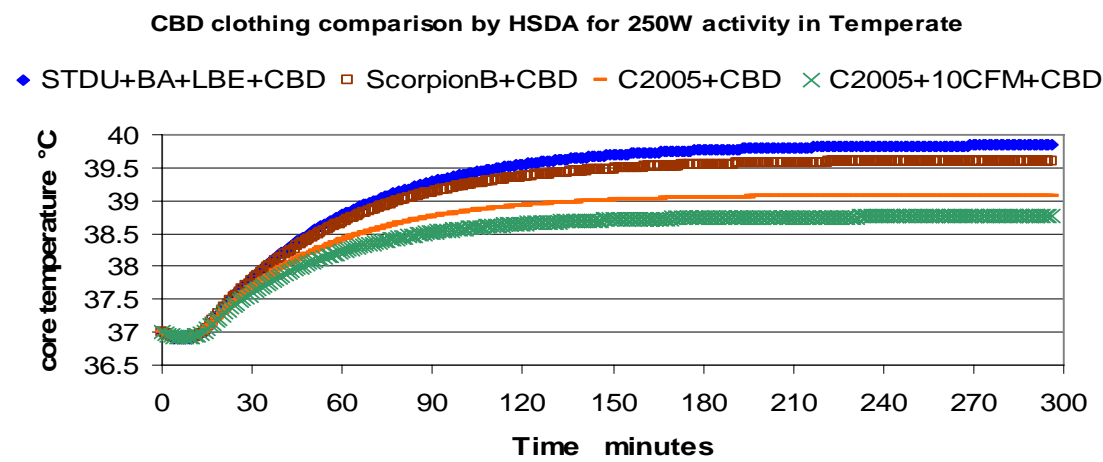
Figure 5Tc. Core temperature simulated responses by HSDA, SCENARIO_J and Simulink2NM for 425W nominal activities in CBD clothing in a temperate summer environment

CBD clothing comparison by HSDA for 425W activity in Temperate

◆ STDU+BA+LBE+CBD ☐ Scorpion B+CBD — C2005+CBD ✕ C2005+10CFM+CBD

CBD clothing comparison by SCENARIO_J for 425W activity in Temperate

◆ STDU+BA+LBE+CBD ☐ Scorpion B+CBD — C2005+CBD ✕ C2005+10CFM+CBD

CBD clothing comparison by Simulink2NM for 425W activity in Temperate

◆ STDU+BA+LBE+CBD ☐ Scorpion B+CBD — C2005+CBD ✕ C2005+10cfm+CBD
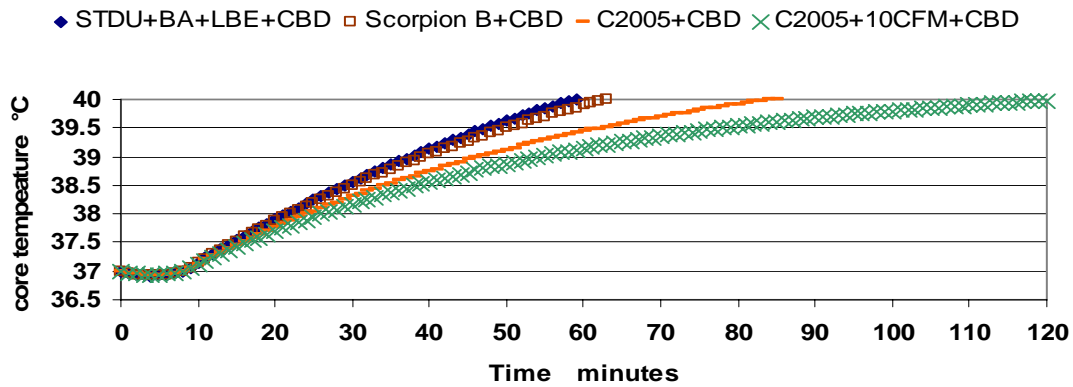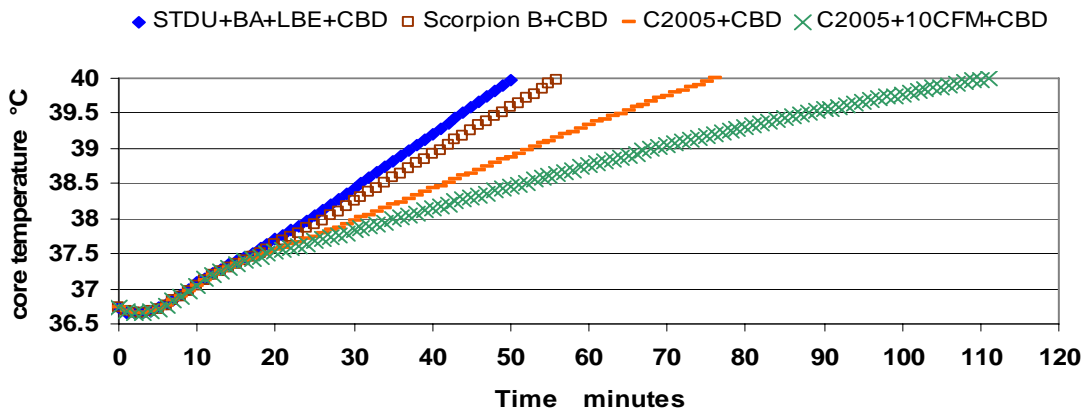
HEART RATE RESPONSES

The cardiovascular effort as indicated by beats per minute for Soldiers wearing the different clothing systems in the three environments as predicted by the SCENARIO_J and Simulink2NM models are presented in Figures 6D, J and T for non-CBD equipped and in Figures 7D, J, and T for CBD equipped Soldiers. For both models, heart rate increases at a given activity with increasing skin blood flow for thermoregulation. Skin blood flow increases primarily with increases in core temperature. Each model has a maximum for skin blood flow (about 90 L/hm^2) that is responsible for the maximum heart rates reached at a given activity.

It is seen that the new clothing designs progressively decreased the effort of the heart in all conditions and activities. This benefit of reduced cardiovascular effort reduction is particularly evident when Soldiers wear CBD gear and for the ventilated clothing design (C2005+CBD+10cfm).

Figure 6Da. Heart rate as predicted by SCENARIO_J for non-CBD clothing in summer desert conditions

NonCBD clothing comparison by SCENARIO_J for 425W activity in Desert

◆ STDU+BA+LBE △ Scorpion A — C2005 ✕ C2005+10CFM

NonCBD clothing comparison by SCENARIO_J for 250W activity in Desert

◆ STDU+BA+LBE △ Scorpion A — C2005 ✕ C2005+10CFM

NonCBD clothing comparison by SCENARIO_J for 150W activity in Desert

◆ STDU+BA+LBE △ Scorpion A — C2005 ✕ C2005+10CFM

-41-
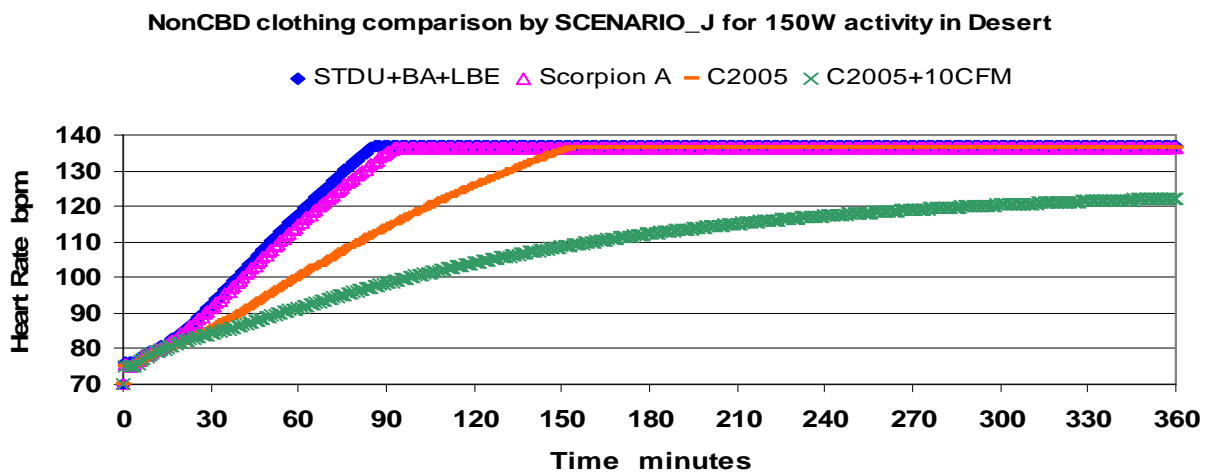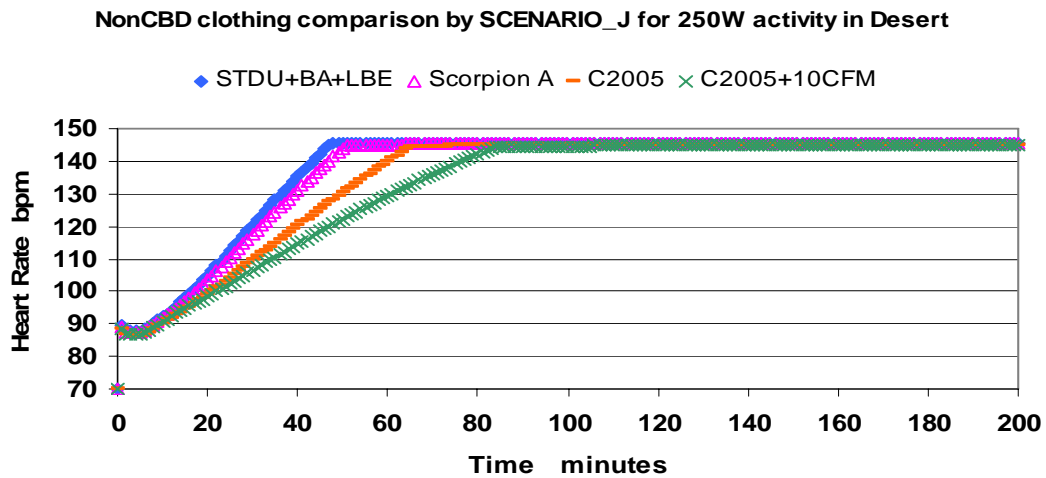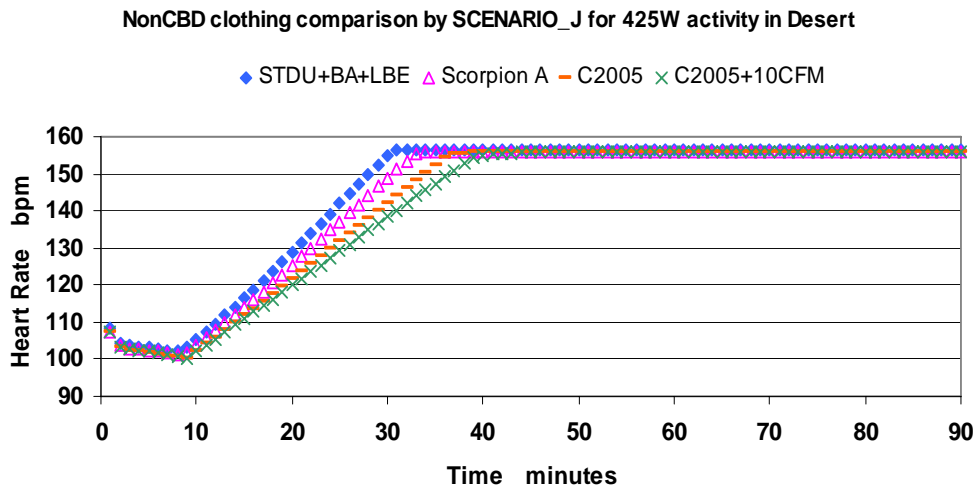
Figure 6Db. Heart rate as predicted by Simulink2NM for non-CBD clothing in summer desert conditions

NonCBD clothing comparison by Simulink for 425W in Desert

NonCBD clothing comparison by Simulink2NM for 250W activity in Desert

NonCBD clothing comparison by Simulink2NM for 150W activity in Desert
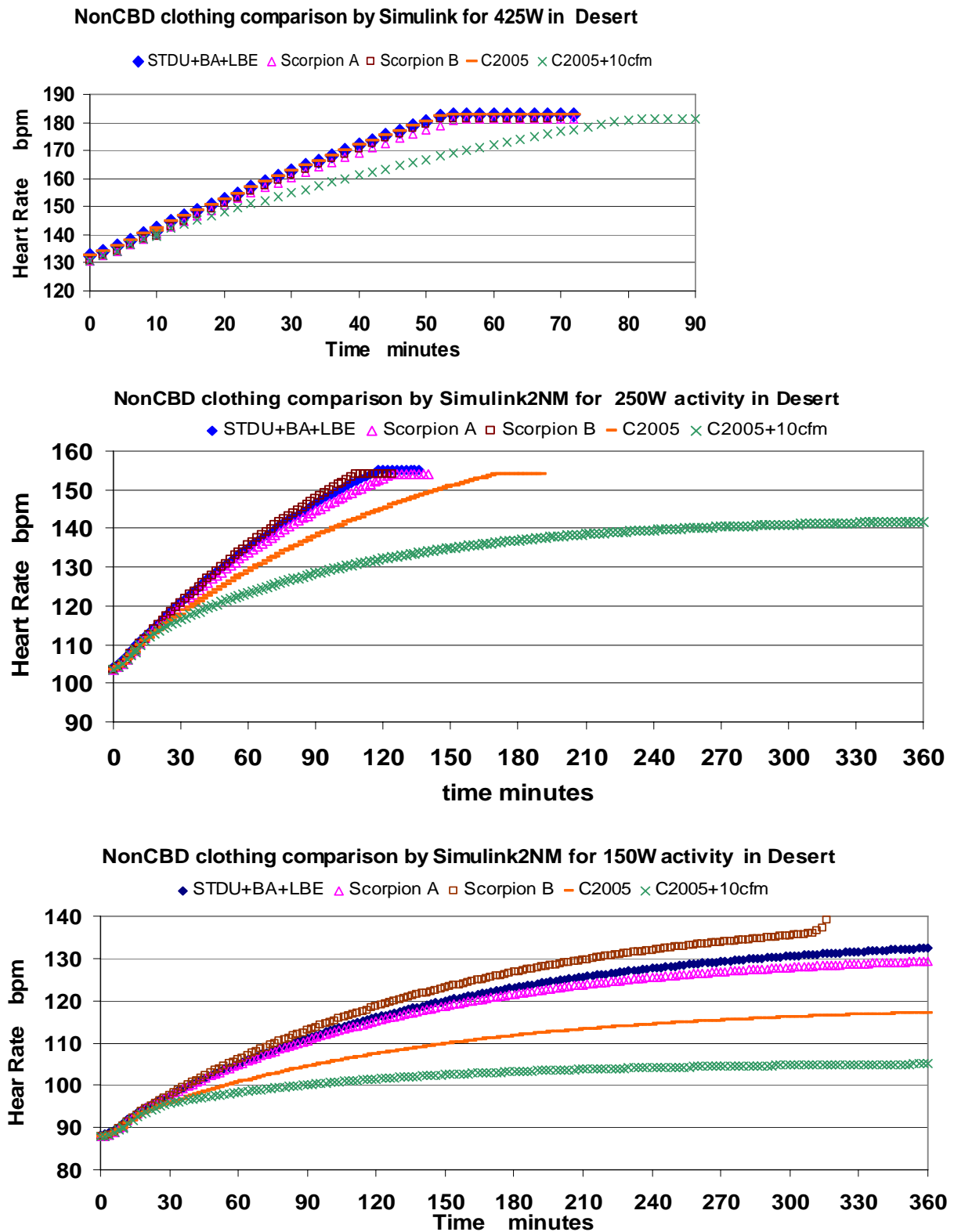
Figure 6Ja. Heart rate as predicted by SCENARIO_J for non-CBD clothing in summer jungle conditions

NonCBD clothing comparison by SCENARIO_J for 425W activity in Jungle

◆ STDU+BA+LBE △ Scorpio A ▬ C2005 ✕ C2005+10CFM

NonCBD clothing comparison by SCENARIO_J for 250W activity in Jungle

◆ STDU+BA+LBE △ Scorpion A ▬ C2005 ✕ C2005+10CFM

NonCBD clothing comparison by SCENARIO_J for 150W activity in Jungle

◆ STDU+BA+LBE △ Scorpion A ▬ C2005 ✕ C2005+10CFM
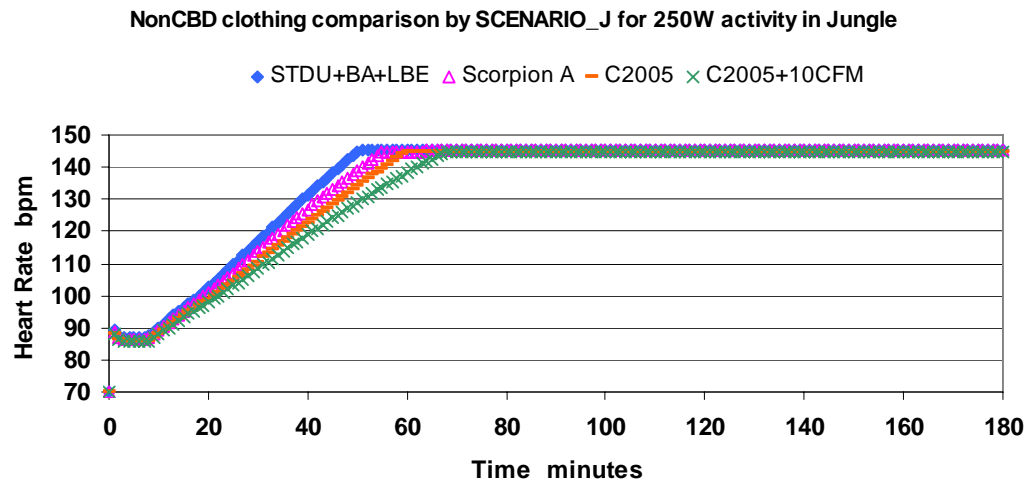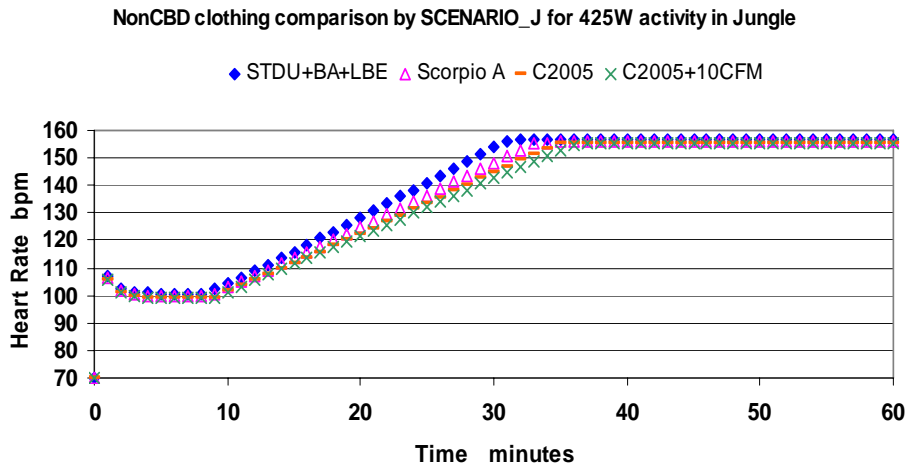
Figure 6Jb. Heart rate as predicted by Simulink2NM for non-CBD clothing in summer jungle conditions

NonCBD clothing comparison by Simulink2NM for 425W activity in Jungle

◆ STDU+BA+LBE △ Scorpion A □ Scorpion B — C2005 ✕ C2005+10cfm

NonCBD clothing comparisonby Simulink2NM for 250W activity in Jungle

◆ STDU+BA+LBE △ Scorpion A □ Scorpion B — C2005 ✕ C2005+10cfm

NonCBD clothing comparison by Simulink2NM for 150w activity in Jungle

◆ STDU+BA+LBE △ Scorpion A □ Scorpion B — C2005 ✕ C2005+10cfm

Figure 6Ta. Heart rate as predicted by SCENARIO_J for non-CBD clothing in summer temperate condition

NonCBD clothing comparison by SCENARIO_J for 425W activity inTemperate

+ STDU+BA+LBE △ Scorpion A — C2005 ✕ C2005+10CFM

NonCBD clothing comparison by SCENARIO_J for 250W activity in Temperate

+ STDU+BA+LBE △ Scorpion A — C2005 ✕ C2005+10CFM

NonCDB clothing comparison by SCENARIO_J for 150W activity in Temperate

+ STDU+BA+LBE △ Scorpion A — C2005 ✕ C05+10CFM
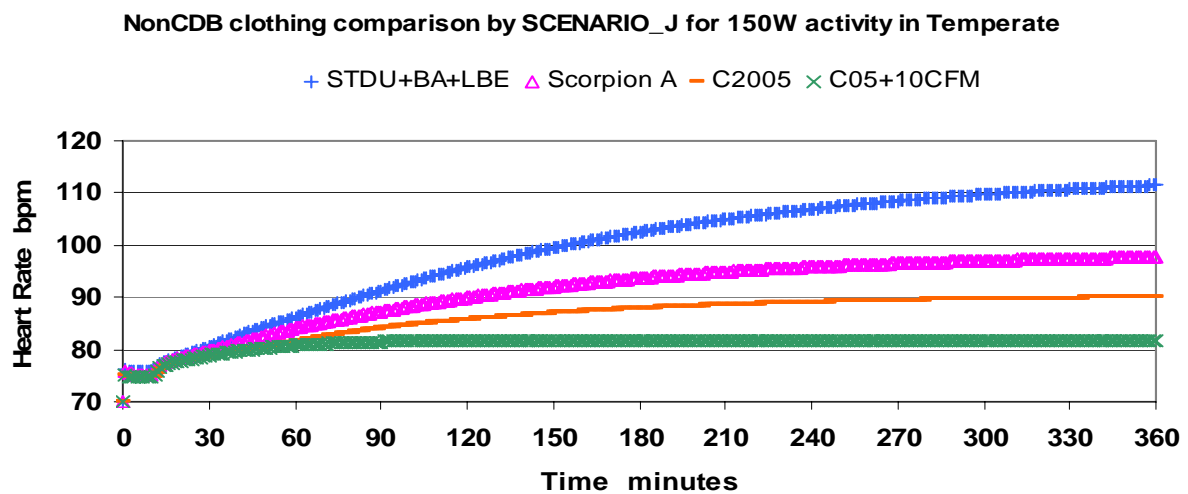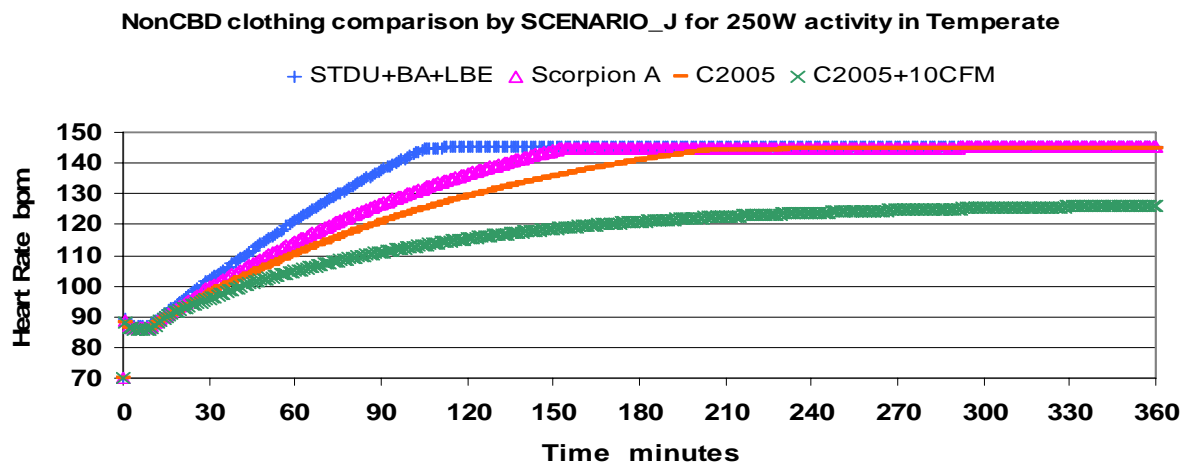
Figure 6Tb. Heart rate as predicted by Simulink2NM for non-CBD clothing in summer temperate condition

NonCBD clothing comparison by Simulink2NM for 425W activity in Temperate

◆ STDU+BA+LBE △ Scorpion A □ Scorpion B — C2005 ✕ C2005+10cfm

NonCBD clothing comparison by Simulink2NM for 250W activity in Temperate

◆ STDU+BA+LBE △ Scorpion A □ Scorpion B — C2005 ✕ C2005+10cfm

NonCBD clothing comparison by Simulink2NM for 150W activity in Temperate

◆ STDU+BA+LBE □ Scorpion B — C2005 ✕ C2005+10cfm

Figure 7Da. Heart rate as predicted by SCENARIO_J for CBD clothing in summer desert conditions

CBD clothing comparison by SCENARIO_J for 425W activity in Desert

◆ STDU+BA+LBE+CBD □ Scorpion B+CBD ─ C2005+CBD ✕ C2005+10CFM+CBD

CBD clothing comparison by SCENARIO_J for 250W activity in Desert

◆ STDU+BA+LBE+CBD □ Scorpion B+CBD ─ C2005+CBD ✕ C2005+10CFM+CBD

CBD clothing comparison by SCENARIO_J for 150W activity in Desert

◆ STDU+BA+LBE+CBD □ Scorpion B+CBD ─ C2005+CBD ✕ C2005+10CFM+CBD
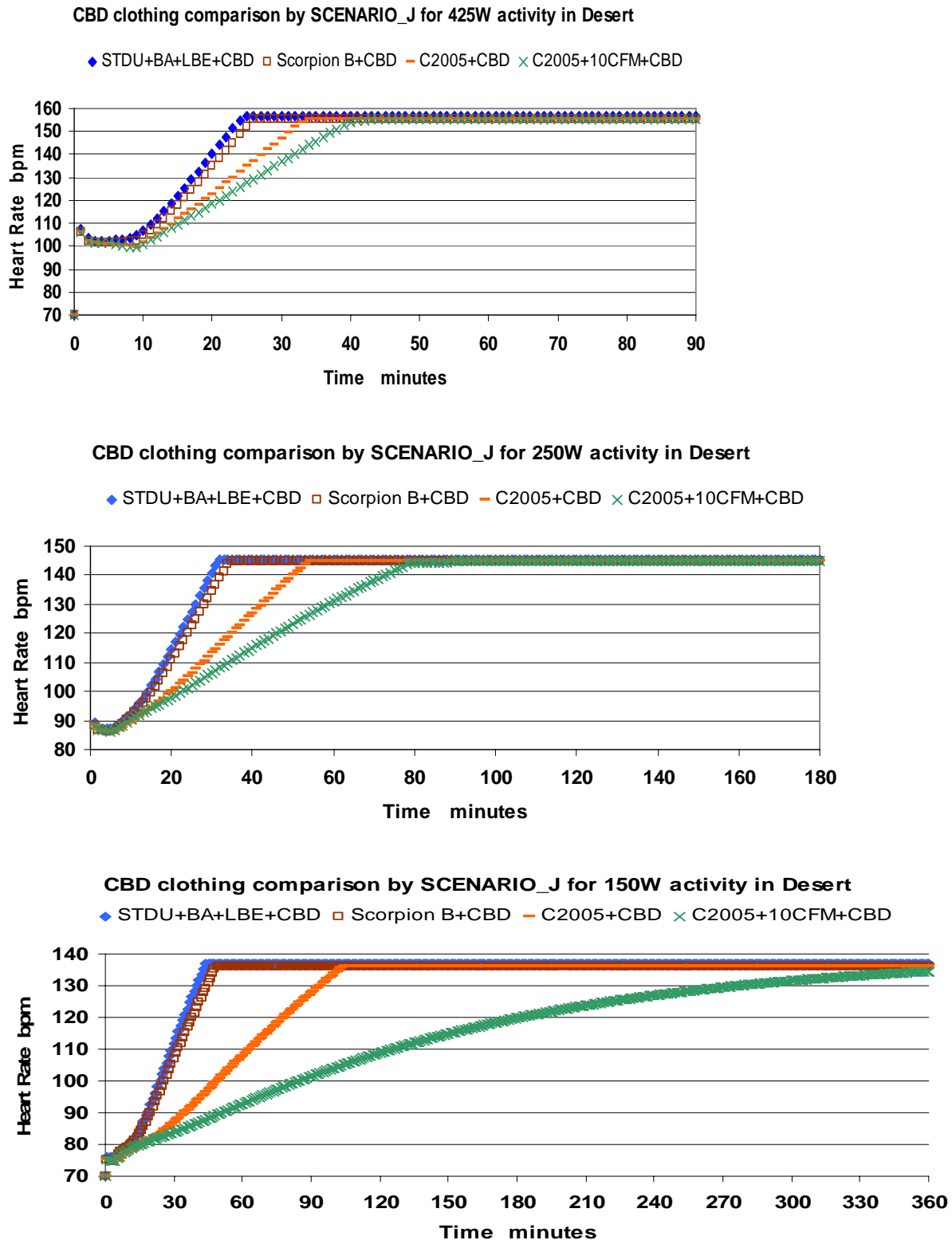
Figure 7Db. Heart rate as predicted by Simulink2NM for CBD clothing in summer desert conditions

CBD clothing comparison by Simulink2NM for 425W activity in Desert

◆ STDU+BA+LBE+CBD □ Scorpion B+CBD — C2005+CBD ✕ C2005+10cfm+CBD

CBD clothing Comparison by Simulink2NM for 250W activity in Desert

◆ STDU+BA+LBE+CBD □ Scorpion B+CBD — C2005+CBD ✕ C2005+10cfm+CBD

CBD clothing comparison by Simulink2NM for 150W activity in Desert

◆ STDU+BA+LBE+CBD ○ Scorpion B+CBD — C2005+CBD ✕ C2005+10cfm+CBD

Figure 7Ja. Heart rate as predicted by SCENARIO_J for CBD clothing in summer jungle conditions

CBD clothing comparison by SCENARIO_J for 425W activity in Jungle

◆ STDU+BA+LBE+CBD ▢ Scorpion B+CBD — C2005+CBD ✕ C2005+10CFM+CBD

CBD clothing comparison by SCENARIO_J for 250W activity in Jungle

◆ STDU+BA+LBE+CBD ▢ Scorpion B+CBD — C2005+CBD ✕ C2005+10CFM+CBD

CBD clothing comparison by SCENARIO_J for 150W activity in Jungle

◆ STDU+BA+LBE+CBD ▢ Scorpion B+CBD — C2005+CBD ✕ C2005+10CFM+CBD

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Figure 7Jb. Heart rate as predicted by Simulink2NM for CBD clothing in summer jungle conditions

CBD clothing comparison by Simulink2NM for 425W activity in Jungle

CBD clothing comparison by Simulink2NM for 250W activity in Jungle

CBD clothing comparison by Simulink2NM for 150W activity in Jungle

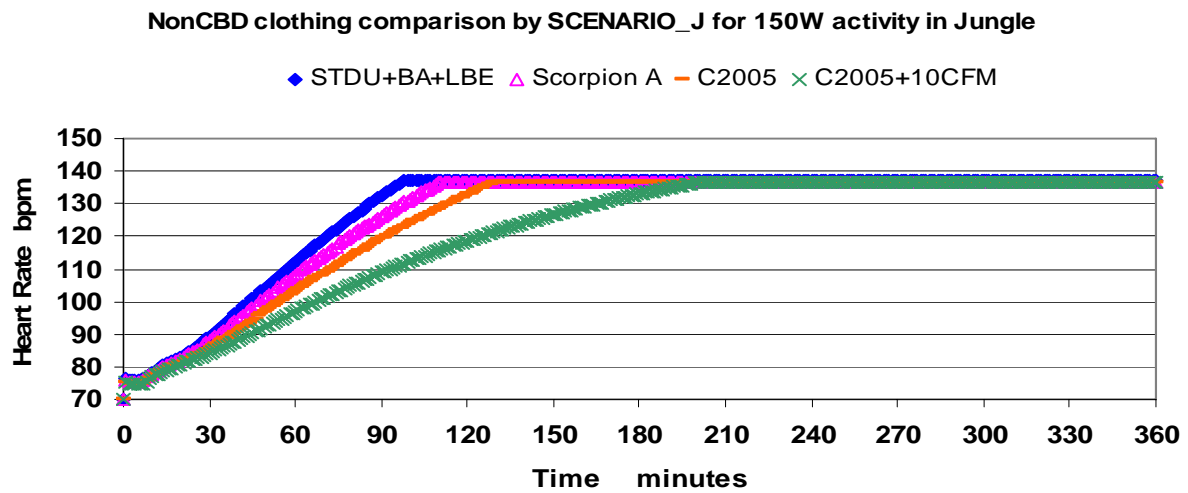# Figure 7Ta. Heart rate as predicted by SCENARIO_J for CBD clothing in summer temperate conditions

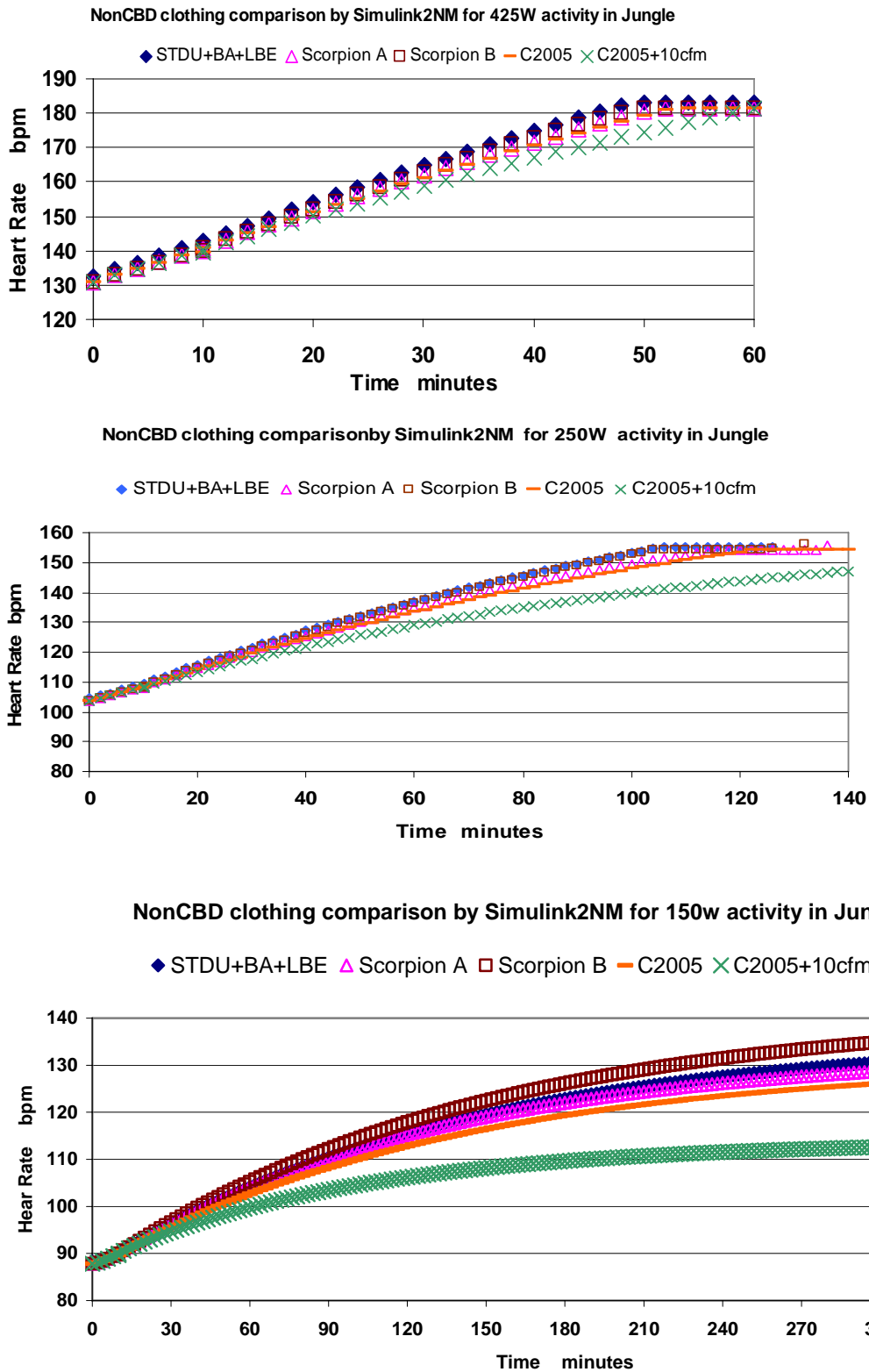### CBD clothing comparison by SCENARIO_J for 425W activity inTemperate

◆ STDU+BA+LBE+CBD   ☐ Scorpion B+CBD   — C2005+CBD   ✕ C2005+10CFM+CBD

CBD clothing comparison by SCENARIO_J for 250W activity in Temperate

◆ STDU+BA+LBE+CBD   ☐ Scorpion B   — C2005+CBD   ✕ C2005+10CFM+CBD

CBD clothing comparison by SCENARIO_J for 150W activity inTemperate

◆ STDU+BA+LBE+CBD   ☐ Scorpion B+CBD   — C2005+CBD   ✕ C2005+10CFM+CBD

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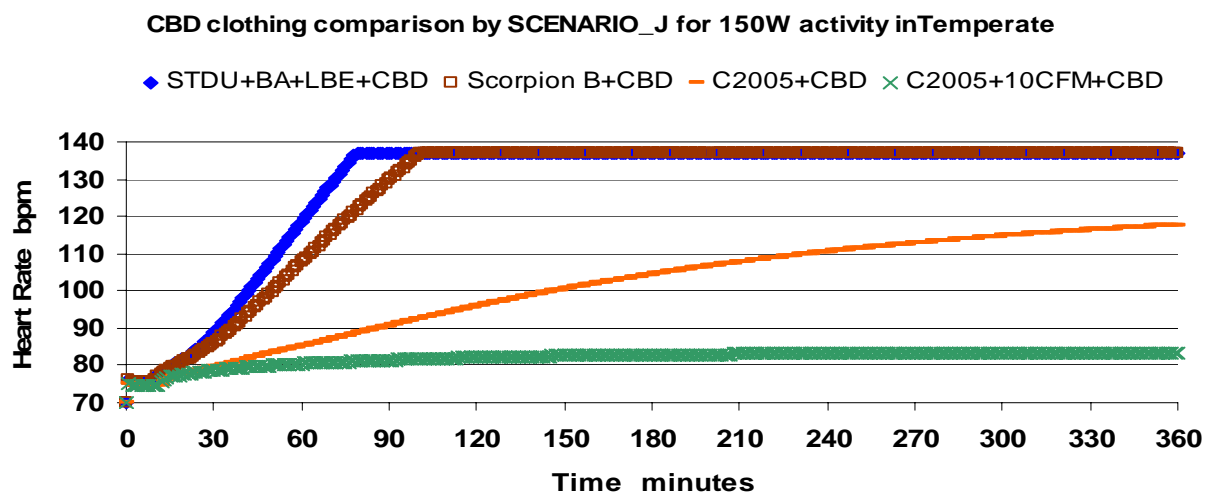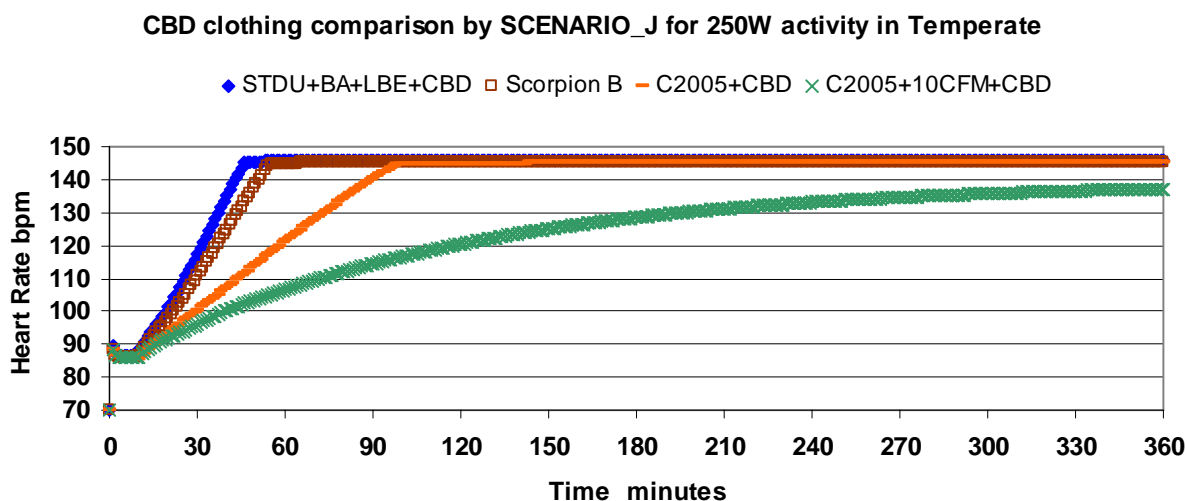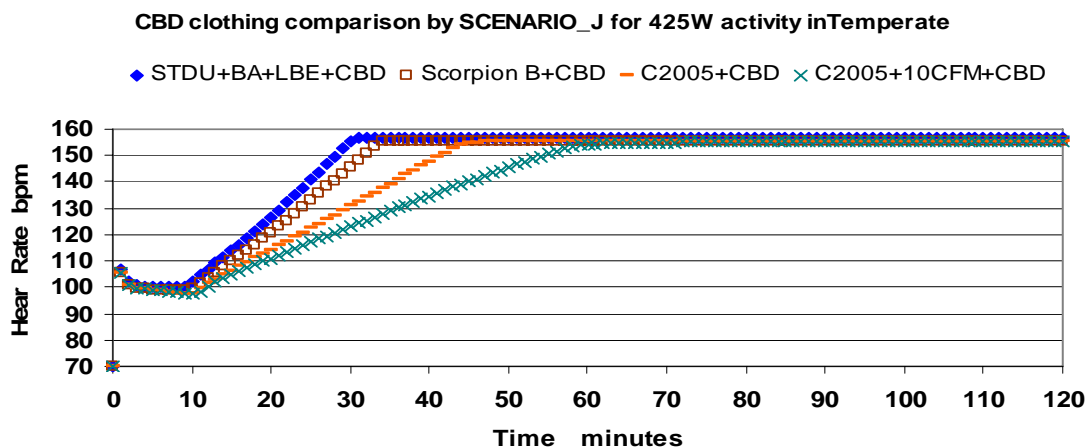
Figure 7Tb. Heart rate as predicted by Simulink2NM for CBD clothing in summer temperate conditions

CBD clothing comparison by Simulink2NM for 425W in Temperate
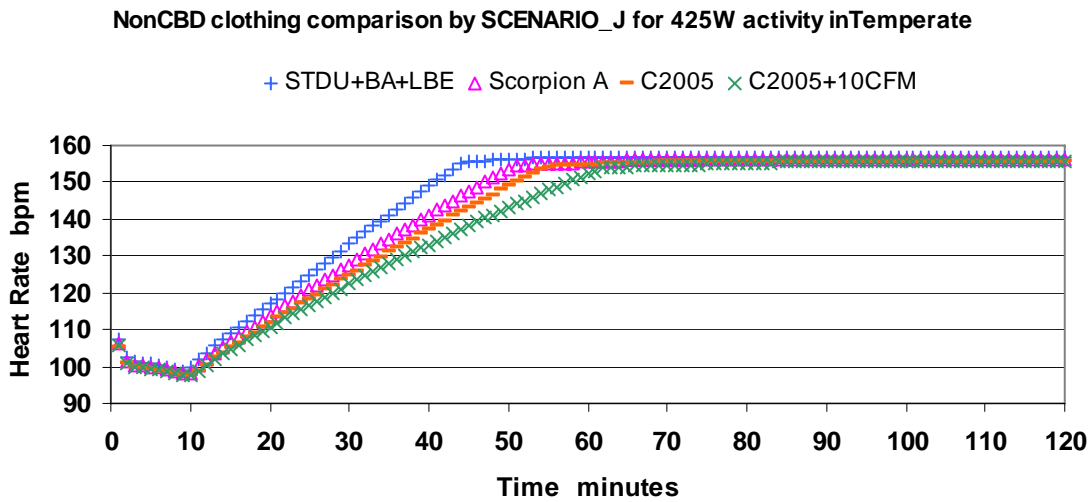
◆ STDU+BA+LBE+CBD □ Scorpion B+CBD — C2005+CBD ✕ C2005+10cfm+CBD

CBD clothing comparison by Simulink2NM for 250W in Temperate

◆ STDU+BA+LBE+CBD □ Scorpion B+CBD — C2005+CBD ✕ C2005+10cfm+CBD

CBD clothing comparison Simulink2NM for 150W activity in Temperate

◆ STDU+BA+LBE+CBD □ Scorpion B+CBD — C2005+CBD ✕ C2005+10cfm+CBD

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TOTAL WATER LOSS

The thermoregulatory effort as indicated by total water loss for Soldiers wearing the different clothing systems in the three environments as predicted by the SCENARIO_J and Simulink2NM models are presented in Figure 8D, J, and T for non-CBD equipped and in Figures 9D, J, and T for CBD equipped Soldiers. The units are liters (L). At low activity levels the differences in water losses are small or non existent between the clothing systems but with increased activity the differences increase. In that respect the water loss responses are similar to those of Tcr. Overall the new designs in uniforms progressively decrease total water loss in all conditions and activities. This reduced water loss benefit potential is particularly evident for the ventilated clothing design (C2005+10cfm).

Figure 8Da. Cumulative water loss as predicted by SCENARIO_J for non-CBD clothing in summer desert conditions

NonCBD clothing comparison by SCENARIO_J for 425W activity in Desert

◆ STDU+BA+LBE △ Scorpion A ▬ C2005 ✕ C2005+10CFM

NonCBD clothing comparison by SCENARIO_J for 250W activity in Desert

◆ STDU+BA+LBE △ Scorpion A ▬ C2005 ✕ C2005+10CFM

NonCBD clothing comparison by SCENARIO_J for 150W activity in Desert

◆ STDU+BA+LBE △ Scorpion A ▬ C2005 □ C2005+10CFM
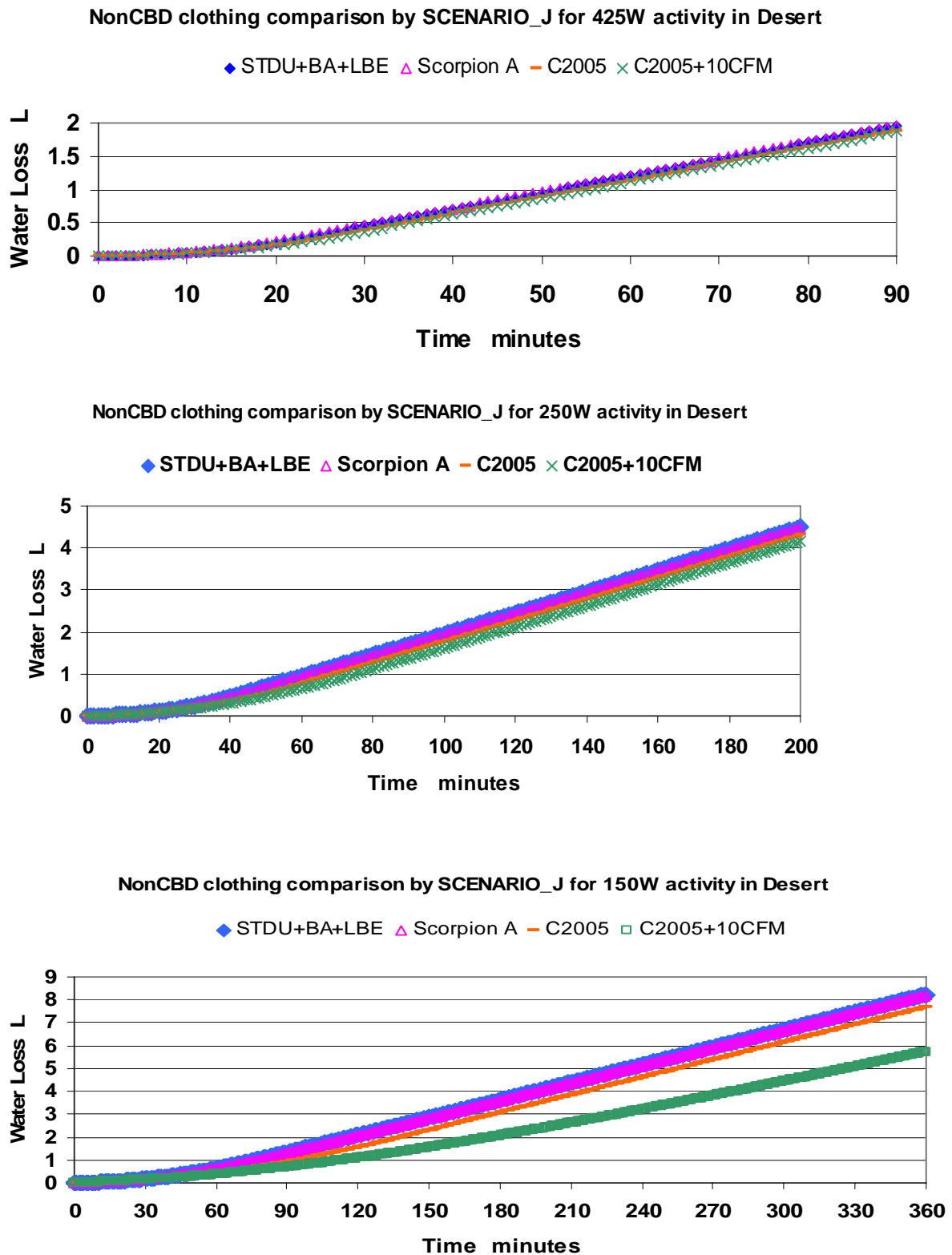
Figure 8Db. Cumulative water loss as predicted by Simulink2NM for non-CBD clothing in summer desert conditions

NonCBD clothing comparison of water loss for 425W activity in Desert

◆ STDU+BA+LBE △ Scorpion A □ Scorpion B — C2005 ✕ C2005+10cfm

NonCBD clothing comparison by Simulink2NM for 250W activity in Desert

◆ STDU+BA+LBE △ Scorpion A □ Scorpion B — C2005 ✕ C2005+10cfm

NonCBD clothing comparison by Simulink2NM for 150W activity in Desert

◆ STDU+BA+LBE △ Scorpion A □ Scorpion B — C2005 ✕ C2005+10cfm
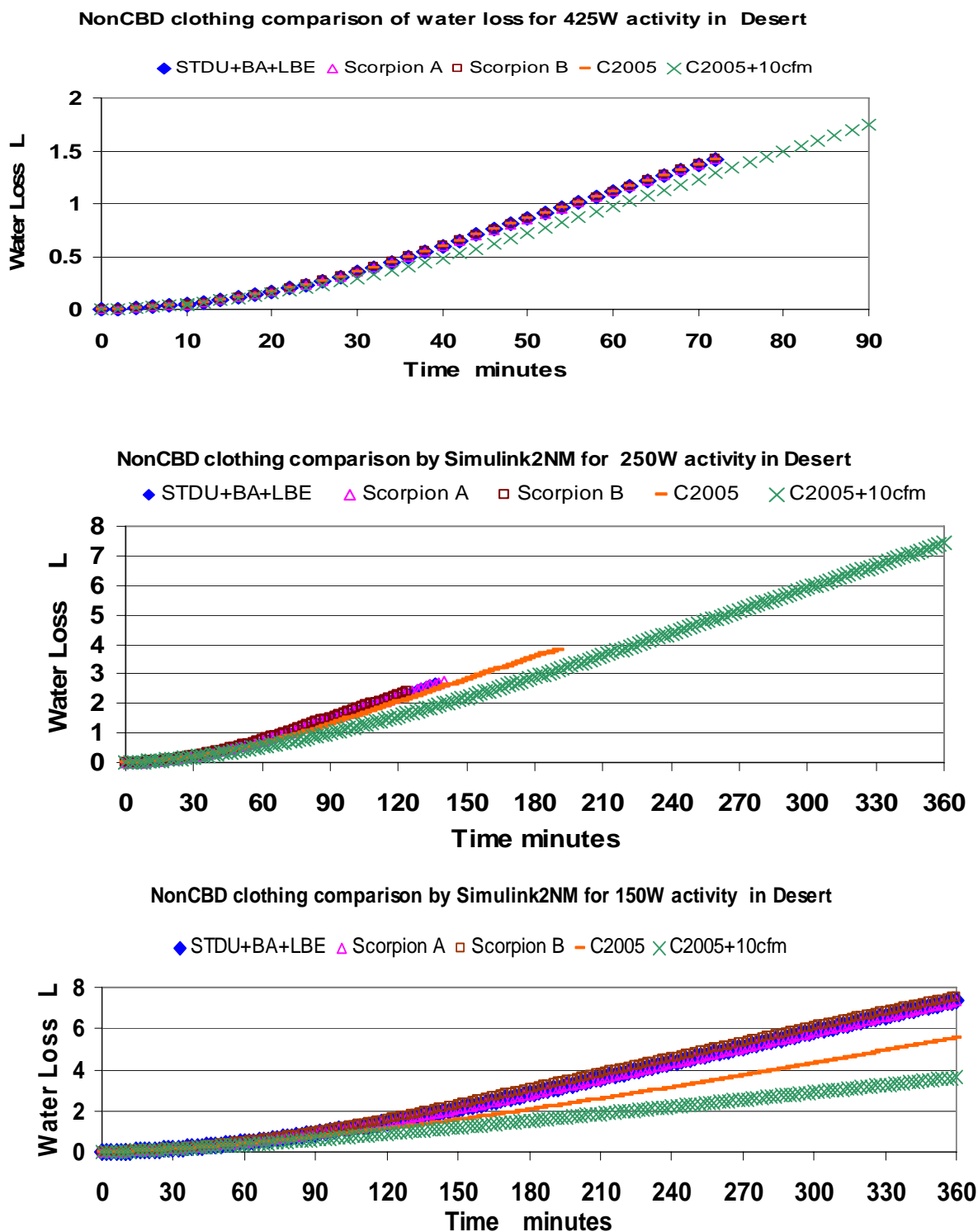
Figure 8Ja. Cumulative water loss as predicted by SCENARIO_J for non-CBD clothing in summer jungle conditions

NonCBD clothing comparison by SCENARIO_J for 425W activity in Jungle

NonCBD clothing comparison by SCENARIO_J for 250W activity in Jungle

NonCBD clothing comparison by SCENARIO_J for 150W activity in Jungle

Figure 8Jb. Cumulative water loss as predicted by Simulink2NM for non-CBD clothing in summer jungle conditions

NonCBD clothing comparison by Simulink for 425w acitivity in Jungle

NonCBD clothing comparison by Simulink2NM for 250W activity in Jungle

NonCBD clothing comparison by Simulink2NM for 150W activity in Jungle

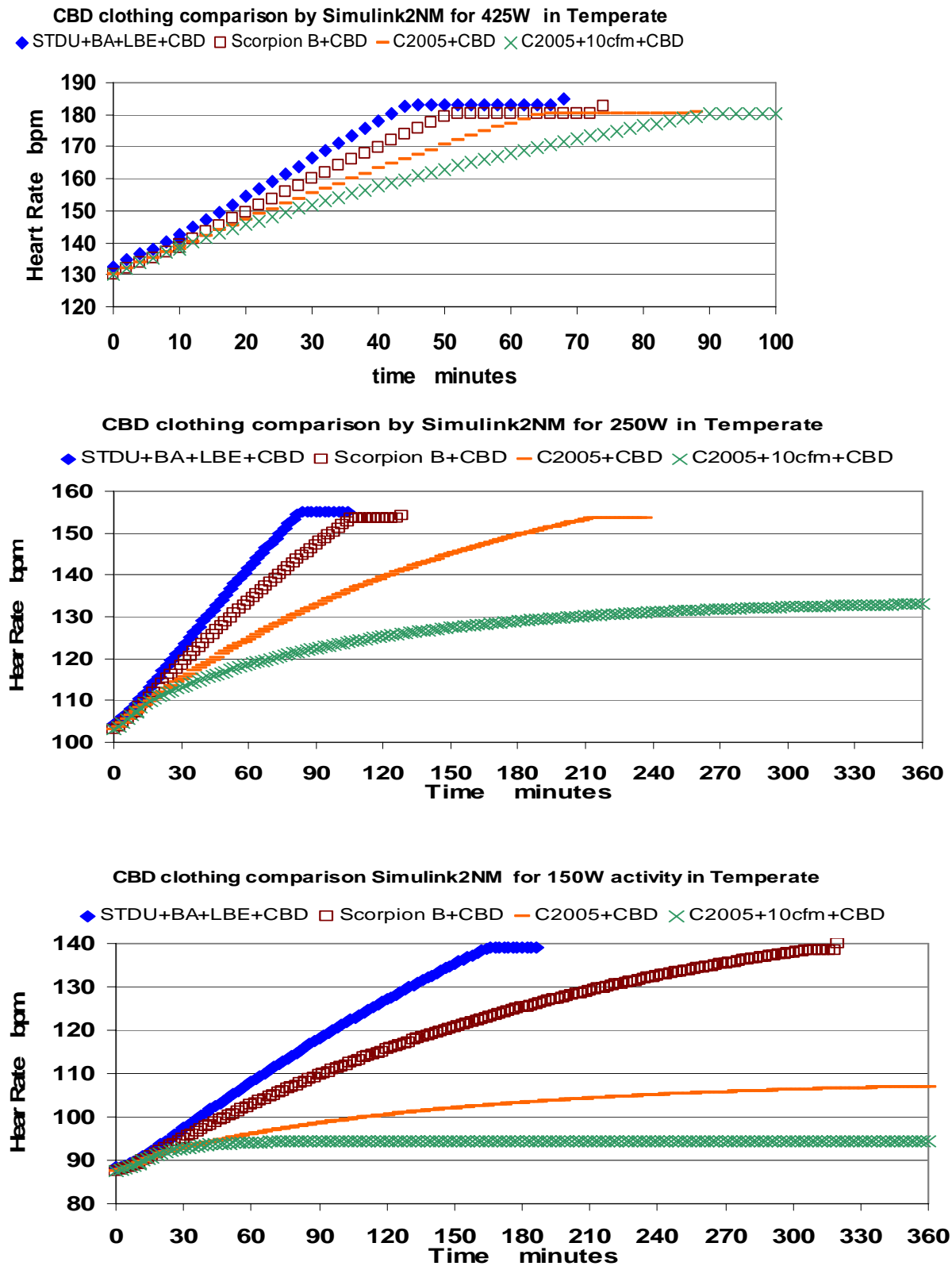**Figure 8Ta. Cumulative water loss as predicted by SCENARIO_J for non-CBD clothing in summer temperate conditions**

NonCBD clothing comparison by SCENARIO_J for 425W activity inTemperate

◆ STDU+BA+LBE △ Scorpion A ━ C2005 ✕ C2005+10CFM

NonCBD clothing comparison by SCENARIO_J for 250W activity in Temperate

◆ STDU+BA+LBE △ Scorpion A ━ C2005 ✕ C2005+10CFM

NonCDB clothing comparison by SCENARIO_J for 150W activity in Temperate

◆ STDU+BA+LBE △ Scorpion A ━ C2005 ✕ C05+10CFM
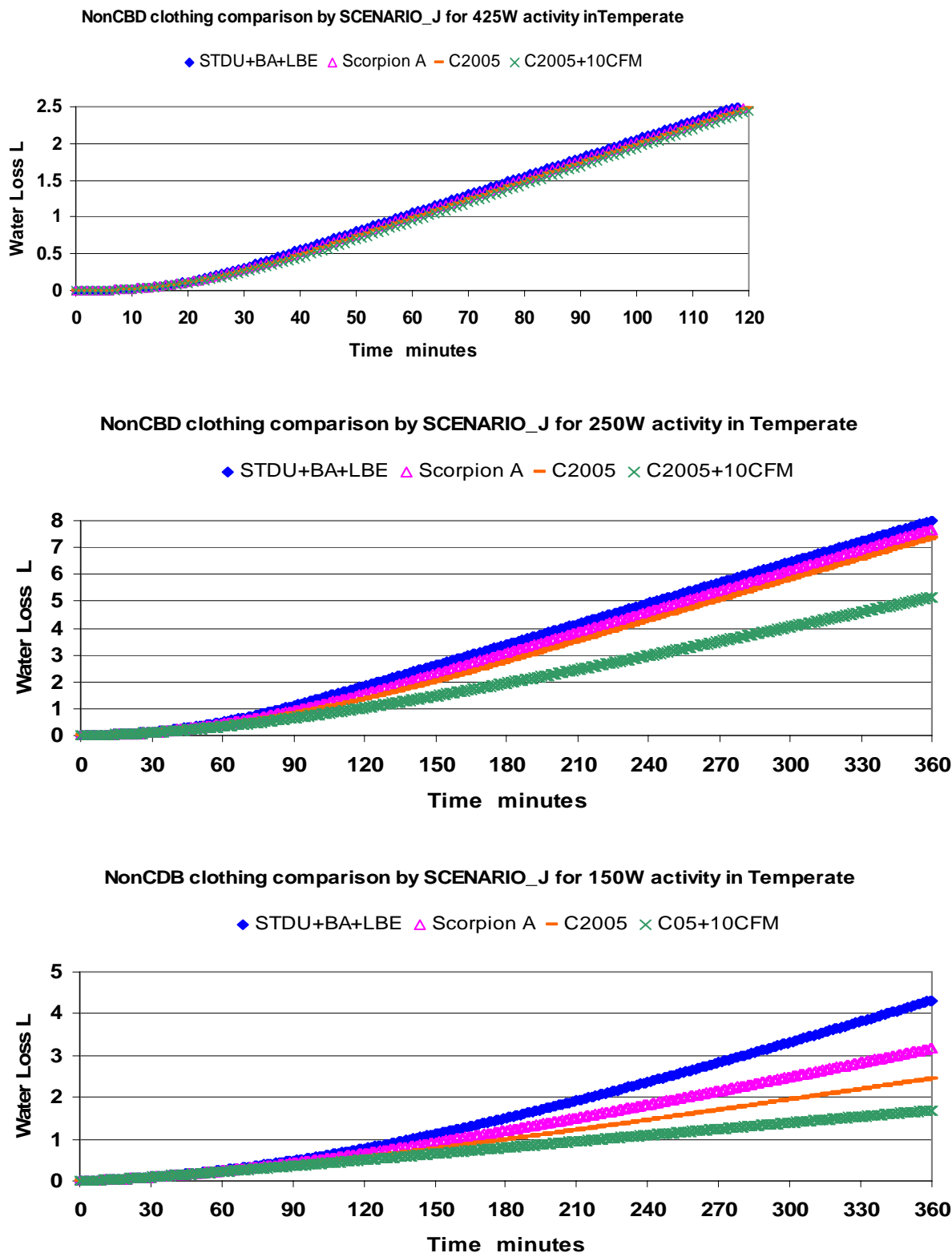
Figure 8Tb. Cumulative water loss as predicted by Simulink2NM for non-CBD clothing in summer temperate conditions

NonCBD clothing comparison by Simulink2NM for 425W activity in Temperate

◆ STDU+BA+LBE △ Scorpion A ☐ Scorpion B ─ C2005 ✕ C2005+10cfm

NonCBD clothing comparison by Simulink2NM for 250W activity in Temperate

◆ STDU+BA+LBE △ Scorpion A ☐ Scorpion B ─ C2005 ✕ C2005+10cfm

NonCBD clothing comparison by Simulink2NM for 150W activity in Temperate

◆ STDU+BA+LBE ☐ Scorpion B ─ C2005 ✕ C2005+10cfm

Figure 9Da. Cumulative water loss as predicted by SCENARIO_J for CBD clothing in summer desert conditions

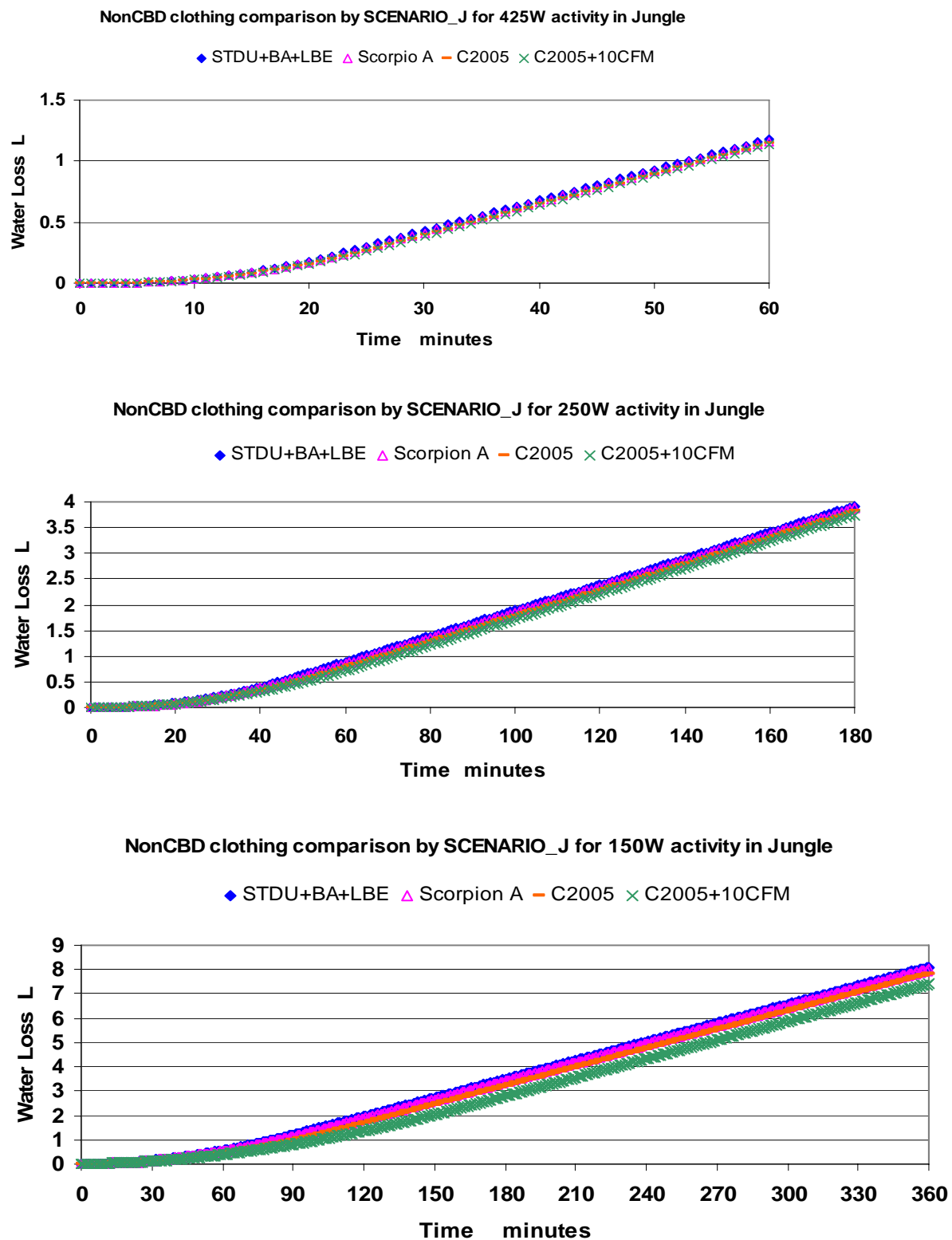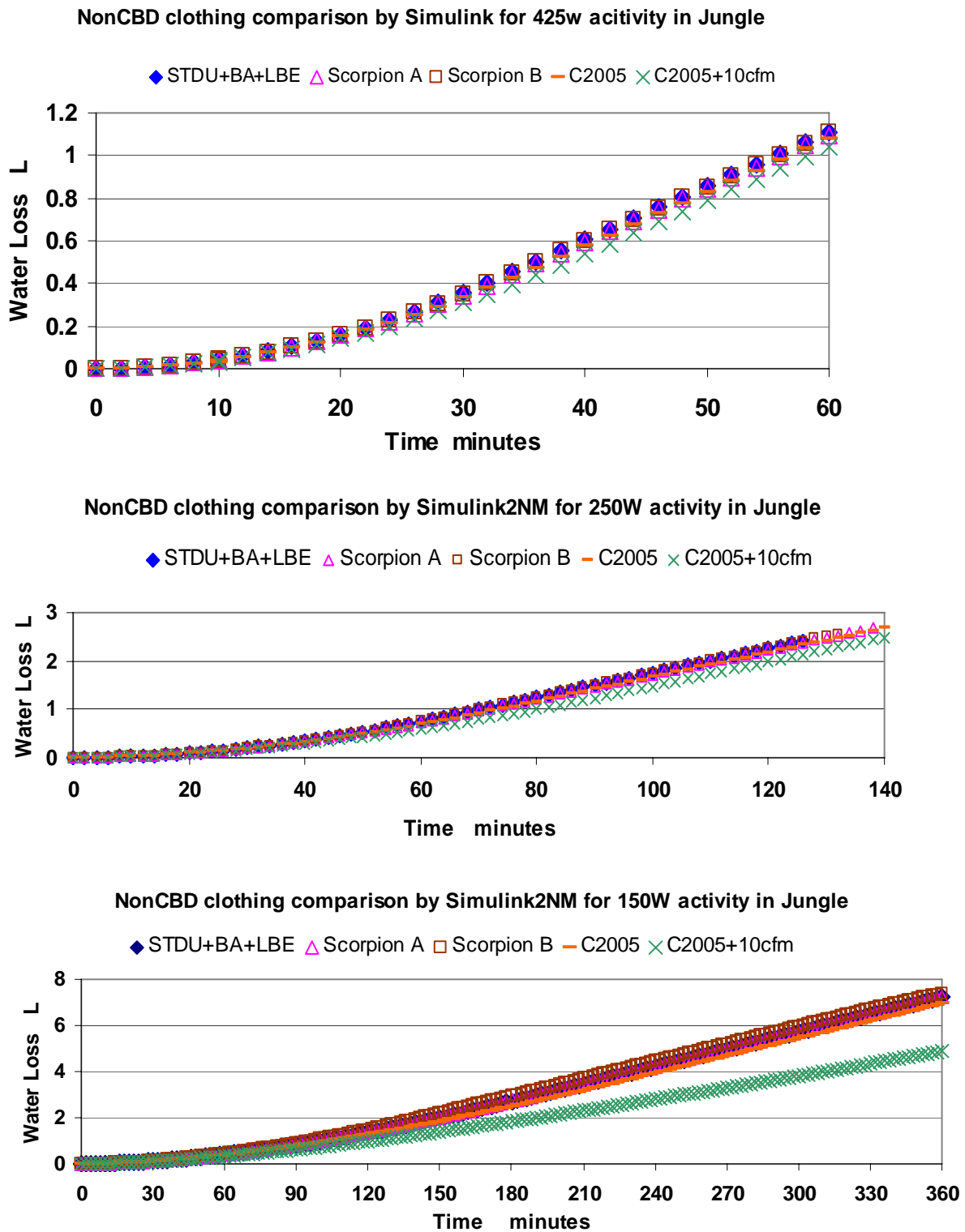### CBD clothing comparison by SCENARIO_J for 425W activity in Desert

◆ STDU+BA+LBE+CBD □ Scorpion B+CBD — C2005+CBD ✕ C2005+10CFM+CBD

CBD clothing comparison by SCENARIO_J for 250W activity in Desert

◆ STDU+BA+LBE+CBD □ Scorpion B+CBD — C2005+CBD ✕ C2005+10CFM+CBD

CBD clothing comparison by SCENARIO_J for 150W activity in Desert

◆ STDU+BA+LBE+CBD □ Scorpion B+CBD — C2005+CBD ✕ C2005+10CFM+CBD

Figure 9Db. Cumulative water loss as predicted by Simulink2NM for CBD clothing in summer desert conditions

CBD Clothing comparison by Simulink2NM for 425W activity in Desert
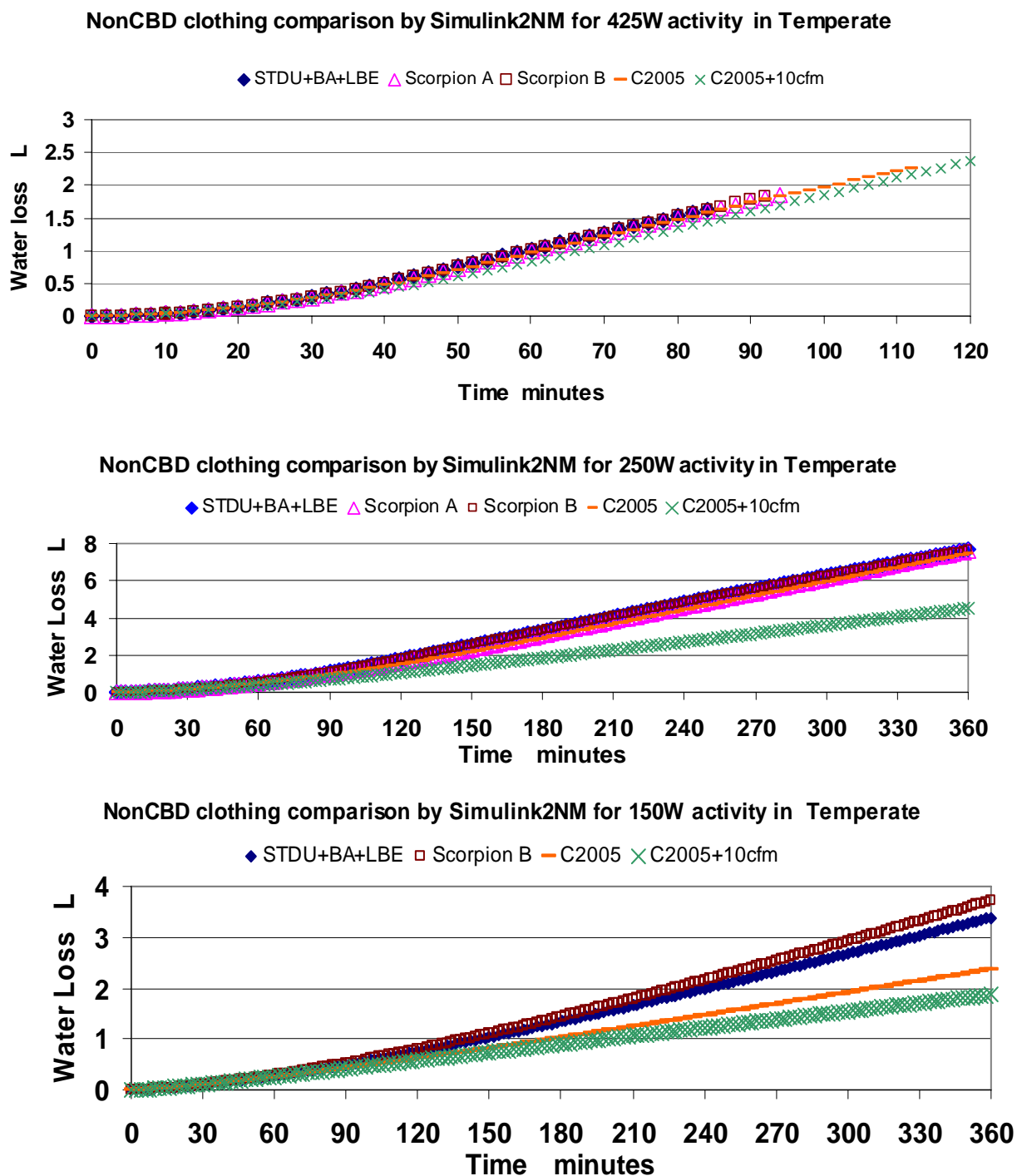
◆ STDU+BA+LBE+CBD ▫ Scorpion B+CBD ▬ C2005+CBD ✕ C2005+10cfm+CBD

CBD clothing comparison by Simulink2NM for 250W activity in Desert

◆ STDU+BA+LBE+CBD ▫ Scorpion B+CBD ▬ C2005+CBD ✕ C2005+10cfm+CBD

CBD clothing comparison by Simulink2NM for 150W activity in Desert

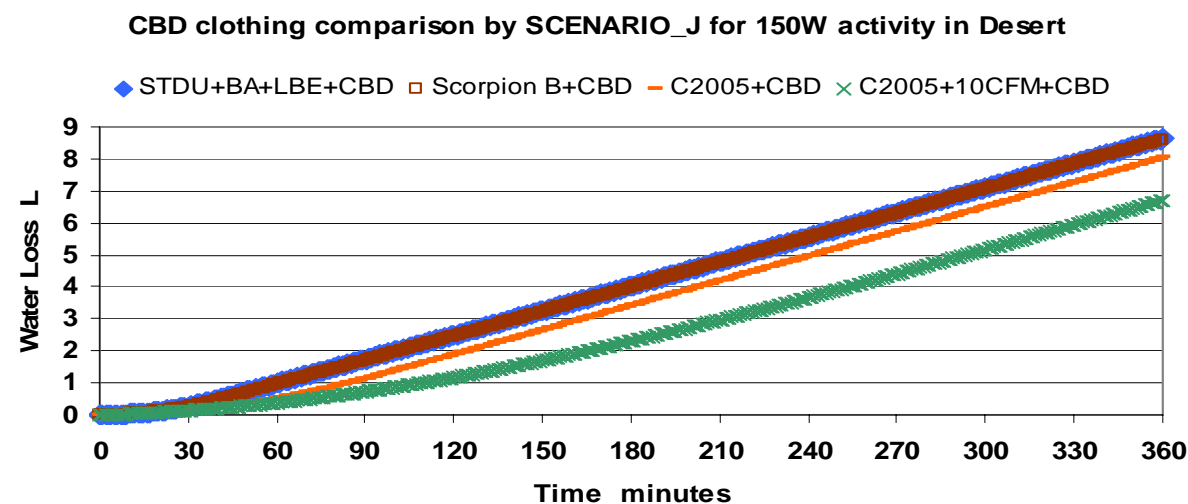◆ STDU+BA+LBE+CBD ▫ Scorpion B+CBD ▬ C2005+CBD ✕ C2005+10cfm+CBD

Figure 9Ja. Cumulative water loss as predicted by SCENARIO_J for CBD clothing in summer jungle conditions

CBD clothing comparison by SCENARIO_J for 425W activity in Jungle

◆ STDU+BA+LBE+CBD □ Scorpion B+CBD ▬ C2005+CBD ✕ C2005+10CFM+CBD

CBD clothing comparison by SCENARIO_J for 250W activity in Jungle

◆ STDU+BA+LBE+CBD □ Scorpion B+CBD ▬ C2005+CBD ✕ C2005+10CFM+CBD

CBD clothing comparison by SCENARIO_J for 150W activity in Jungle

◆ STDU+BA+LBE+CBD □ Scorpion B+CBD ▬ C2005+CBD ✕ C2005+10CFM+CBD
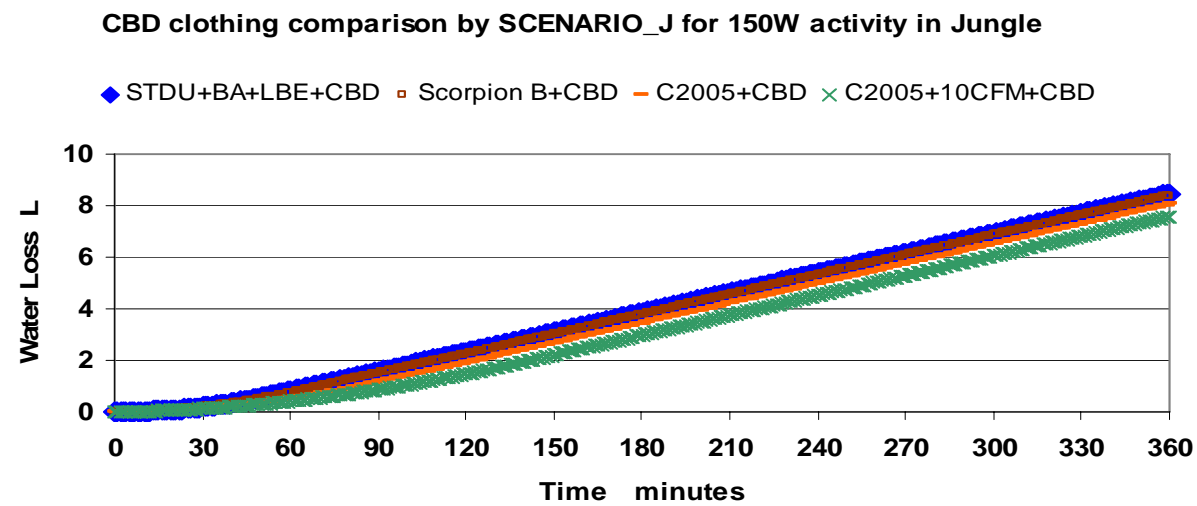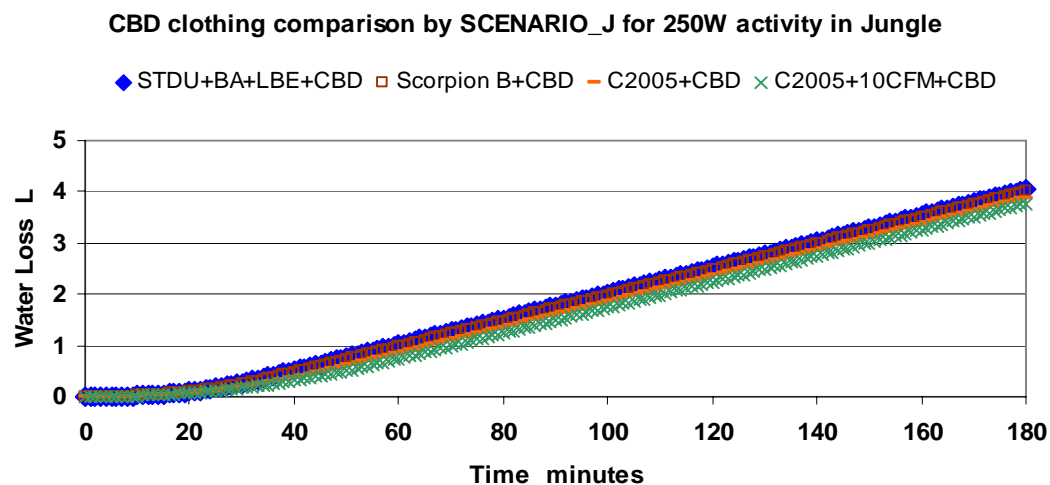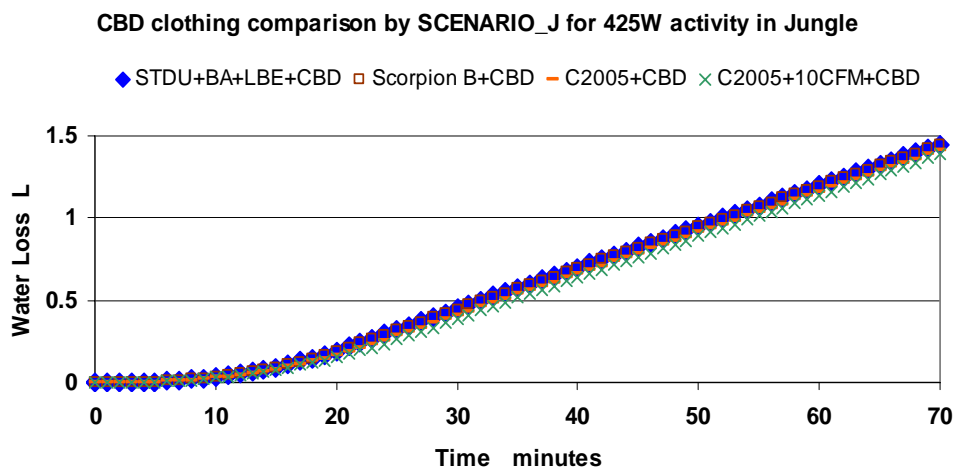
Figure 9Jb. Cumulative water loss as predicted by Simulink2NM for CBD clothing in summer jungle conditions

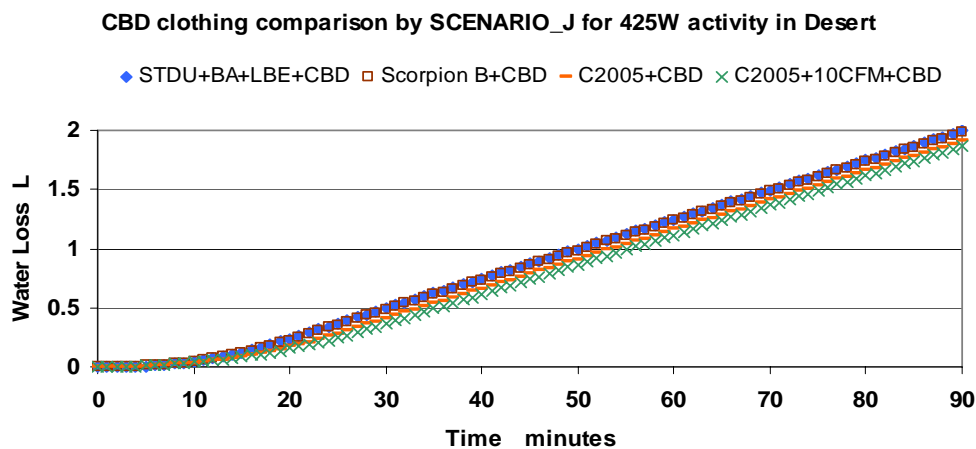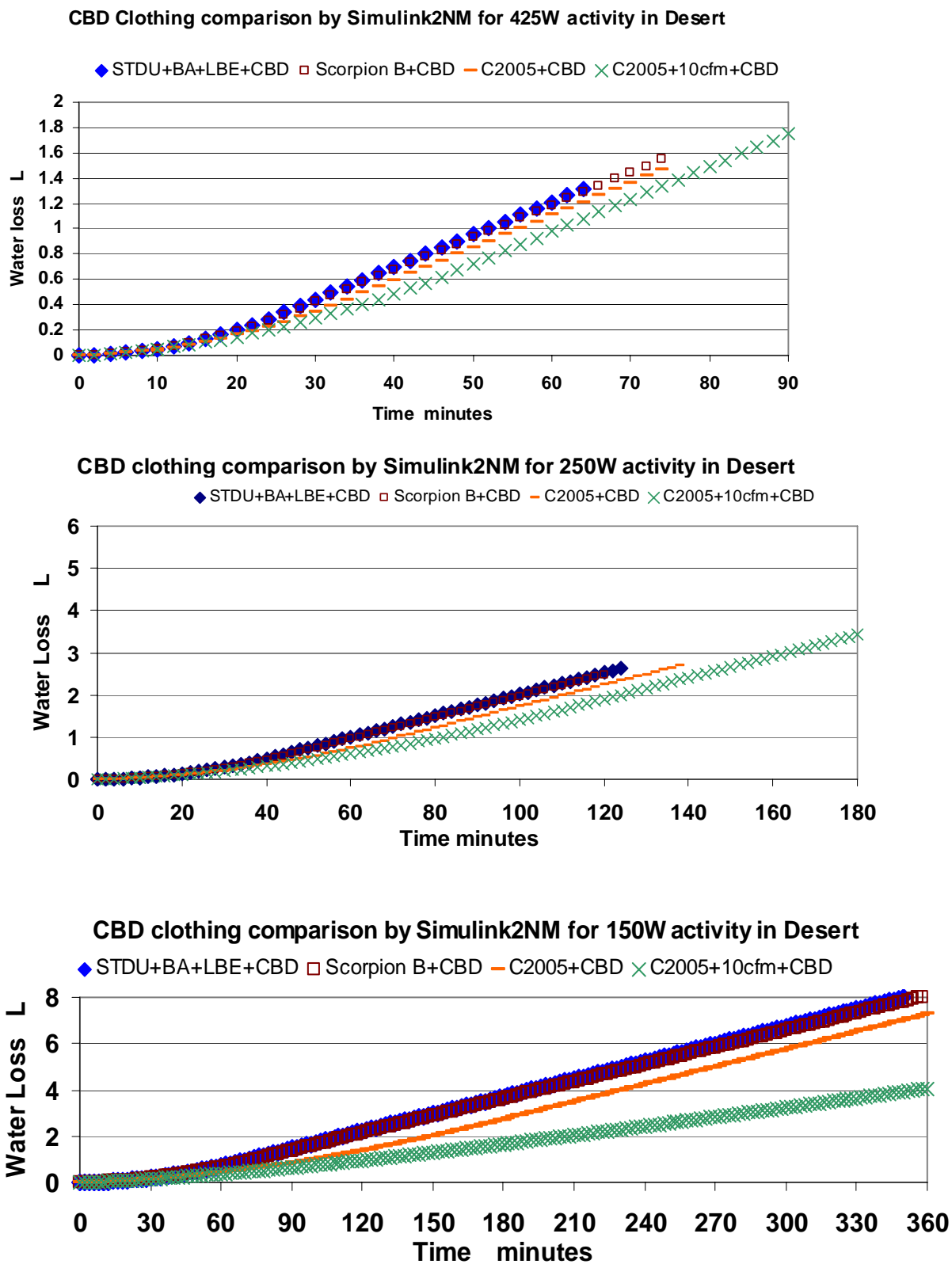CBD clothing comparison by Simulink2NM for 425W activity in Jungle

◆ STDU+BA+LBE+CBD □ Scorpion B+CBD — C2005+CBD ✕ C2005+CBD+10cfm

CBD clothing comparison by Simulink2NM for 250W activity in Jungle

◆ STDU+BA+LBE+CBD □ Scorpion B+CBD — C2005+CBD ✕ C2005+10cfm_CBD

CBD clothing comparison by Simulink2NM for 150w activity in Jungle

◆ STDU+BA+LBE+CBD □ Scorpion B+CBD — C2005+CBD ✕ C2005+10cfm_CBD

Figure 9Ta. Cumulative water loss as predicted by SCENARIO_J for CBD clothing in summer temperate conditions

CBD clothing comparison by SCENARIO_J for 425W activity in Temperate

◆ STDU+BA+LBE+CBD ☐ Scorpion B+CBD — C2005+CBD ✕ C2005+10CFM+CBD

CBD clothing comparison by SCENARIO_J for 250W activity inTemperate

◆ STDU+BA+LBE+CBD △ Scorpion B — C2005+CBD ✕ C2005+10CFM+CBD

CBD clothing comparison by SCENARIO_J for 150W activity inTemperate

◆ STDU+BA+LBE+CBD ☐ Scorpion B+CBD — C2005+CBD ✕ C2005+10CFM+CBD

Figure 9Tb. Cumulative water loss as predicted by Simulink2NM for CBD clothing in summer temperate conditions

CBD clothing comparison by Simulink2NM for 425W activity in Temperate

◆ STDU+BA+LBE+CBD ☐ Scorpion B+CBD — C2005+CBD ✕ C2005+10CFM+CBD

CBD clothing comparison by Simulink2NM for 250W activity in Temperate

◆ STDU+BA+LBE+CBD ☐ Scorpion B+CBD — C2005+CBD ✕ C2005+10cfm+CBD

CBD clothing comparison by Simulink2NM for 150W activity in Temperate

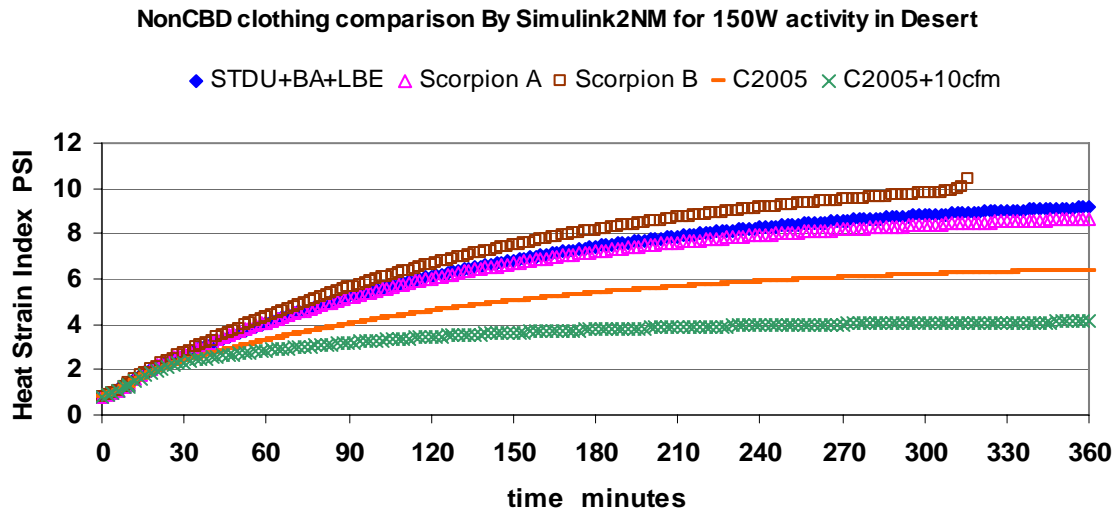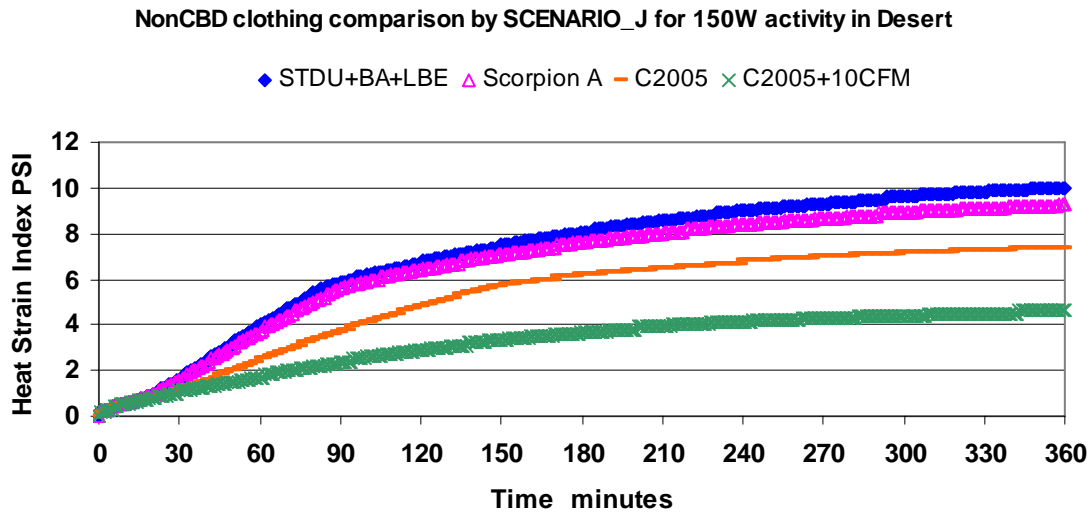◆ STDU+BA+LBE+CBD ○ Scorpion B+CBD — C2005+CBD ✕ C2005+10cfm+CBD

PHYSIOLOGICAL STRAIN INDEX (PSI) FOR HEAT STRESS

The thermoregulatory strain as quantified by the Physiological Strain Index (PSI) (4) for Soldiers wearing the different clothing systems in the three environments as predicted by the SCENARIO_J and Simulink2NM models are presented in Figures 10 and 11. PSI compares the deviations in Tcr and HR caused by stress to the maximum acceptable deviations and combines them into a convenient dimensionless scale. The index 's scale ranges from a minimum of 0 to a maximum of about 10. PSI as used in the following graphs were defined and evaluated as:
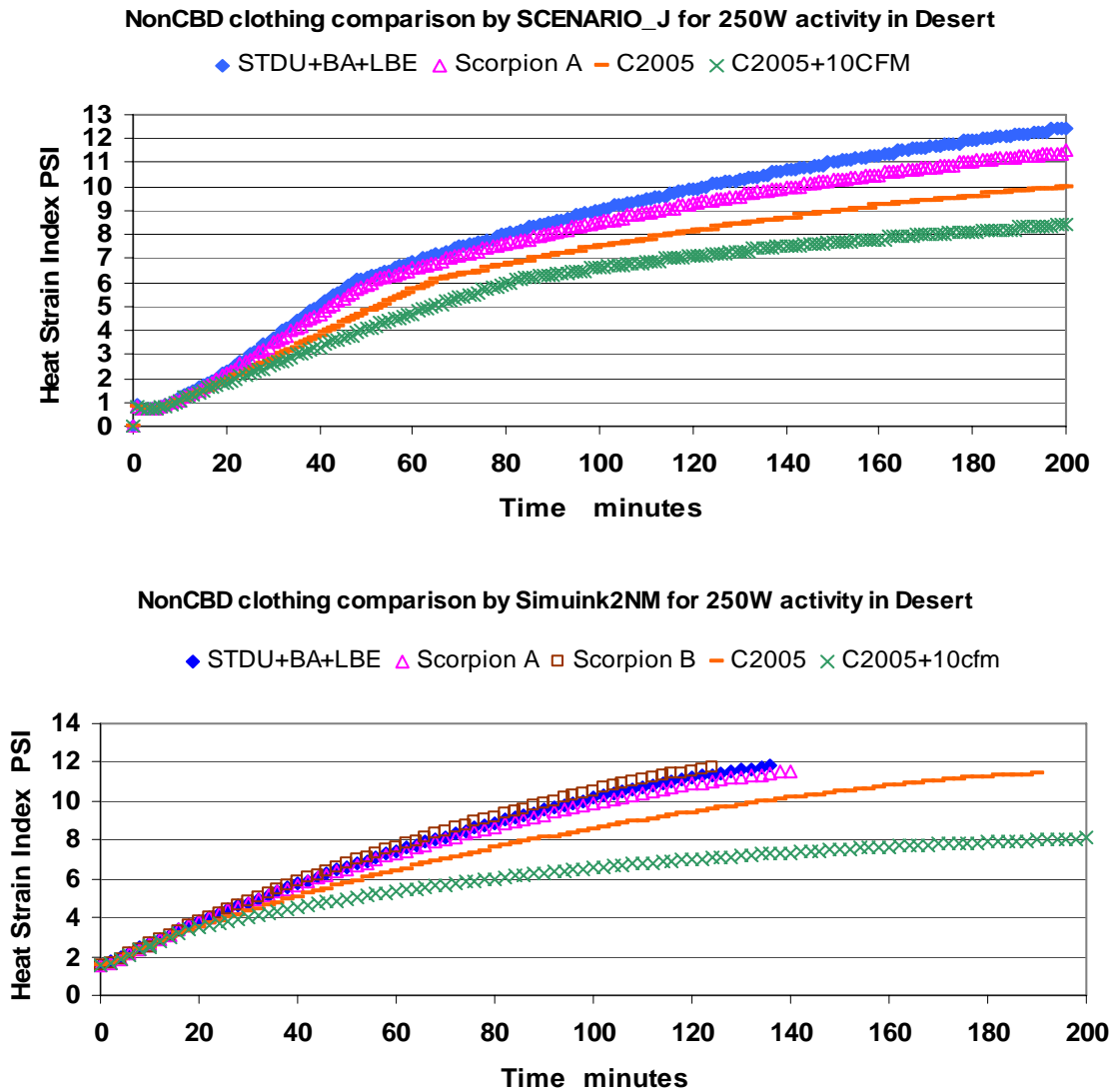
$$PSI = 5(Tcr_t-36.9)/(39.5-36.9) + 5(HR_t-70)/(180-70).$$

Where Tcr_t and HR_t are simultaneous predicted values taken at any simulation time (t). The default values of the initial Tcr as 36.9°C and the initial HR as 70 bpm at a resting physiological state were utilized in this study.

Figure 10Da. Physiological Strain Index (PSI) as predicted by SCENARIO_J and Simulink 2NM for 150W nominal activities in non-CBD clothing in a summer desert environment

NonCBD clothing comparison by SCENARIO_J for 150W activity in Desert

◆ STDU+BA+LBE △ Scorpion A ━ C2005 ✕ C2005+10CFM

NonCBD clothing comparison By Simulink2NM for 150W activity in Desert

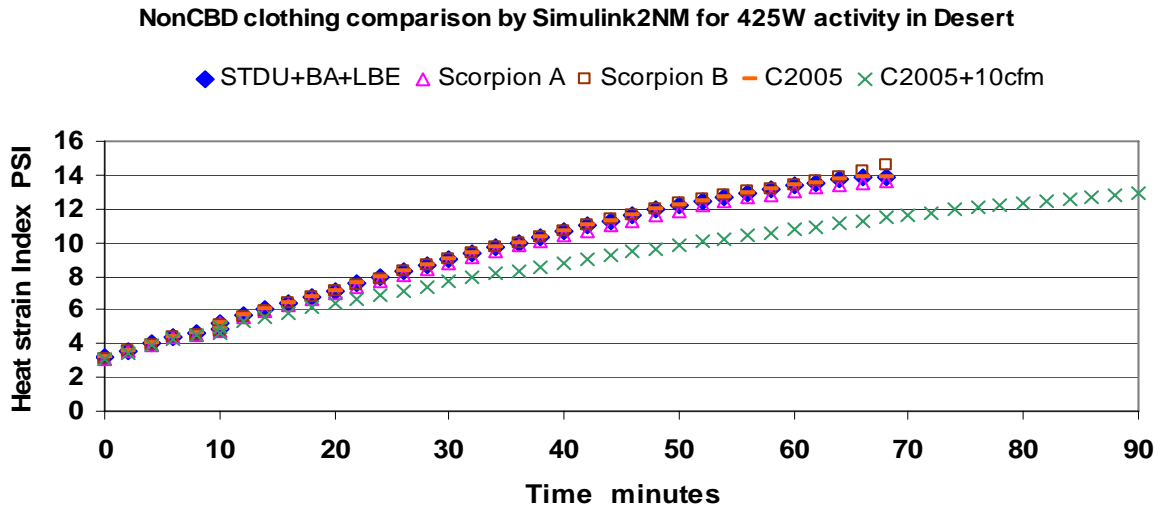◆ STDU+BA+LBE △ Scorpion A ☐ Scorpion B ━ C2005 ✕ C2005+10cfm

Figure 10Db. Physiological Strain Index (PSI) as predicted by SCENARIO_J and Simulink 2NM for 250W nominal activities in non-CBD clothing in a summer desert environment

NonCBD clothing comparison by SCENARIO_J for 250W activity in Desert

◆ STDU+BA+LBE △ Scorpion A ─ C2005 ✕ C2005+10CFM

NonCBD clothing comparison by Simuink2NM for 250W activity in Desert

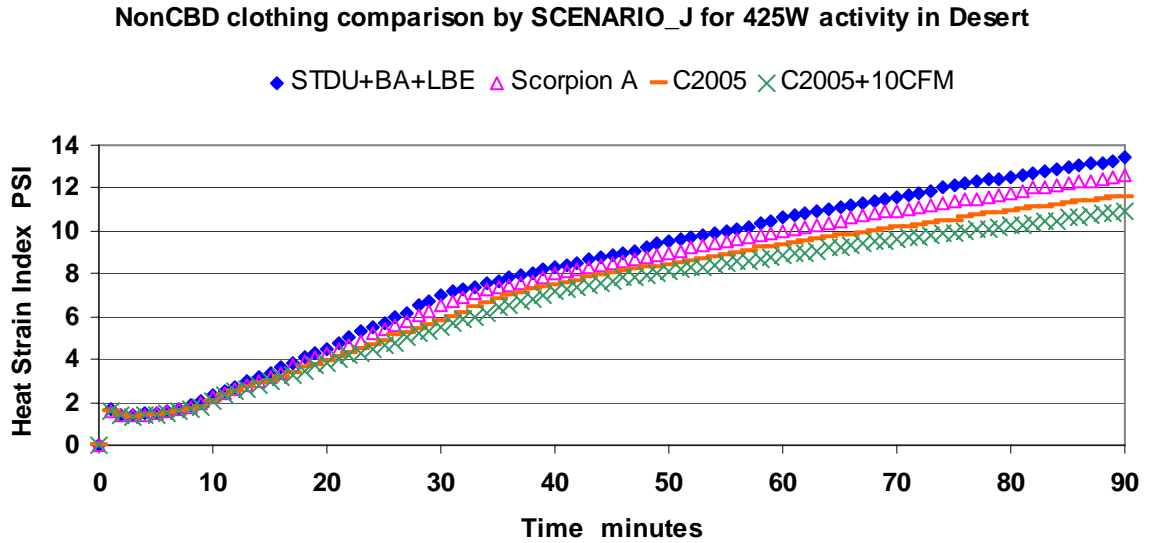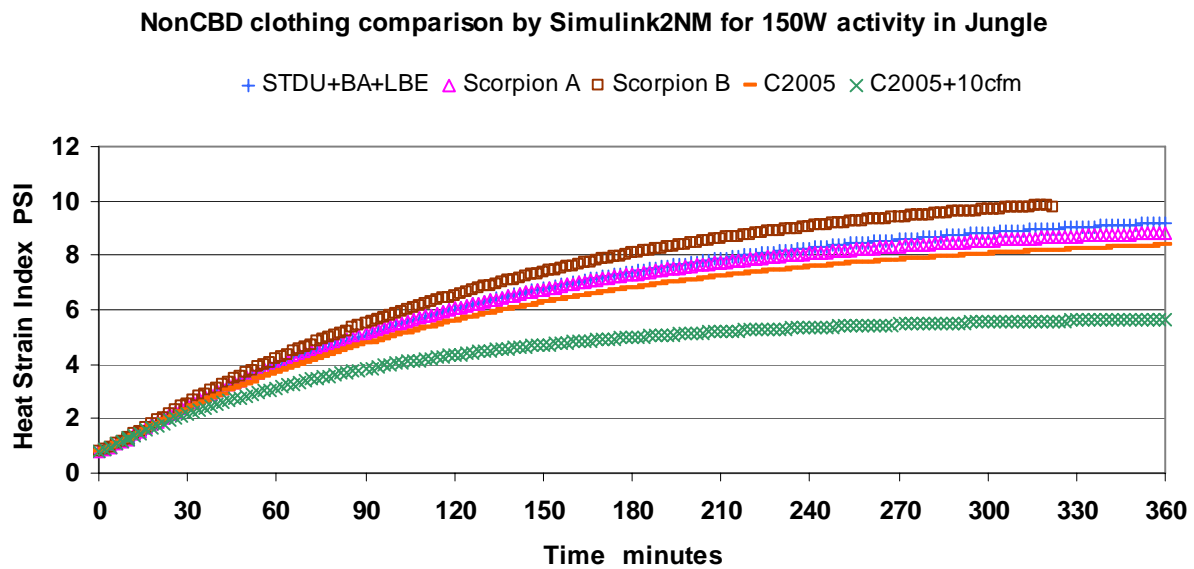◆ STDU+BA+LBE △ Scorpion A □ Scorpion B ─ C2005 ✕ C2005+10cfm

Figure 10Dc. Physiological Strain Index (PSI) as predicted by SCENARIO_J and Simulink 2NM for 425W nominal activities in non-CBD clothing in a summer desert environment

NonCBD clothing comparison by SCENARIO_J for 425W activity in Desert

♦ STDU+BA+LBE △ Scorpion A ─ C2005 ✕ C2005+10CFM

NonCBD clothing comparison by Simulink2NM for 425W activity in Desert

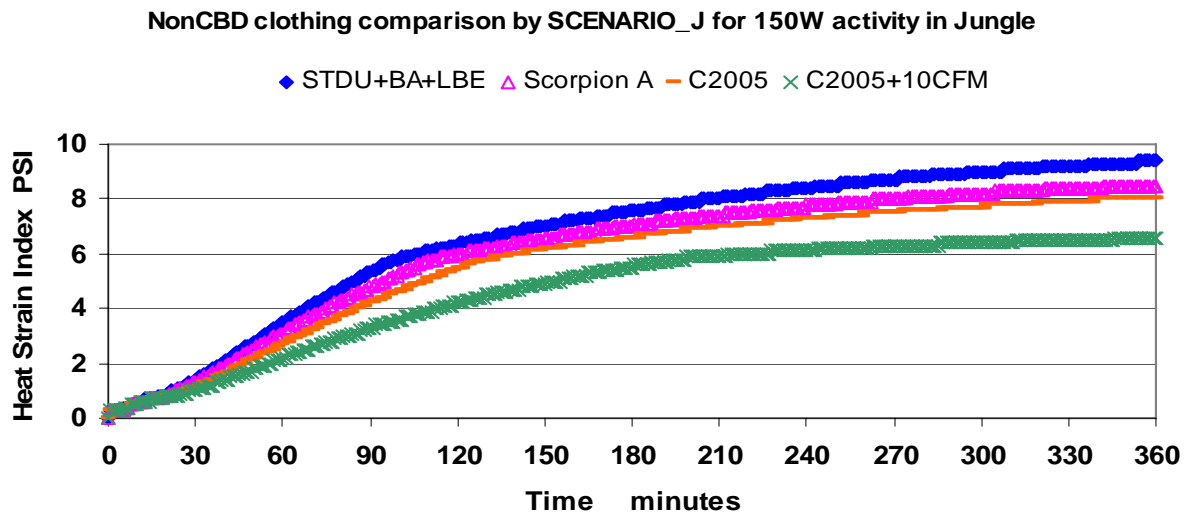♦ STDU+BA+LBE △ Scorpion A ☐ Scorpion B ─ C2005 ✕ C2005+10cfm

Figure 10Ja. Physiological Strain Index (PSI) as predicted by SCENARIO_J and Simulink 2NM for 150W nominal activities in non-CBD clothing in a summer jungle environment

NonCBD clothing comparison by SCENARIO_J for 150W activity in Jungle

◆ STDU+BA+LBE △ Scorpion A ━ C2005 ✕ C2005+10CFM

NonCBD clothing comparison by Simulink2NM for 150W activity in Jungle

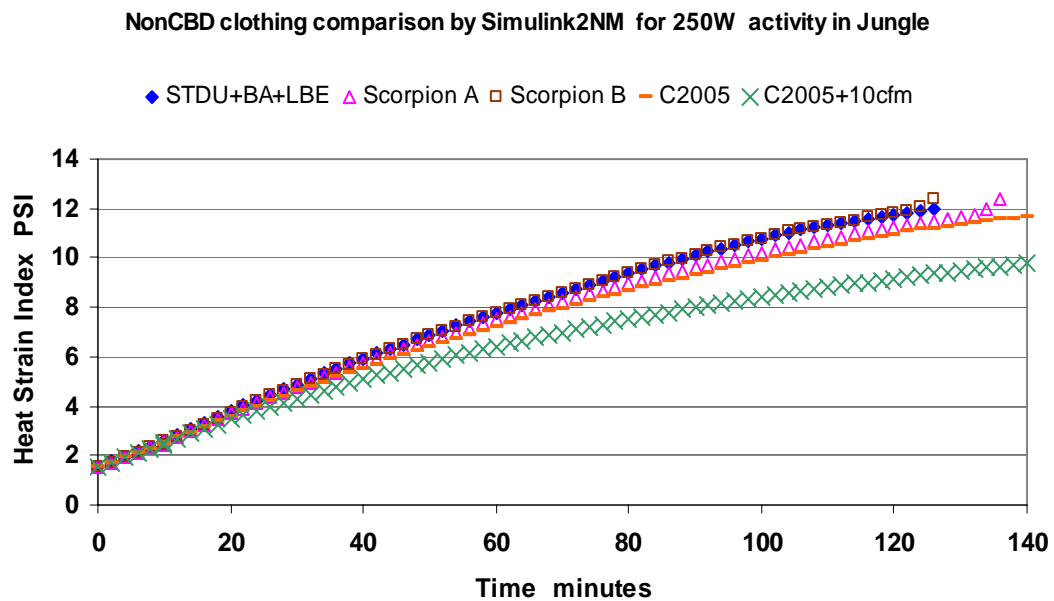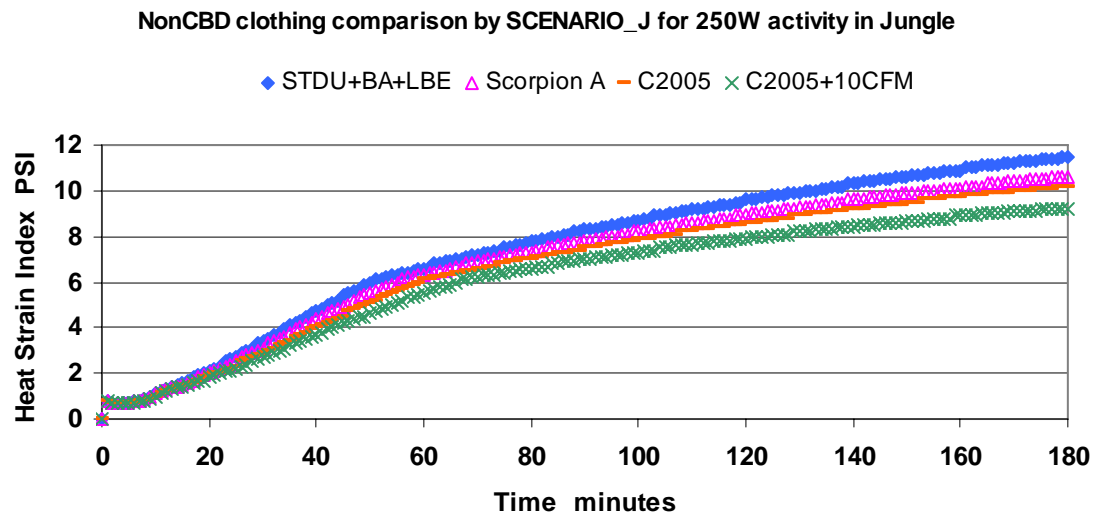+ STDU+BA+LBE △ Scorpion A ▢ Scorpion B ━ C2005 ✕ C2005+10cfm

Figure 10Jb. Physiological Strain Index (PSI) as predicted by SCENARIO_J and Simulink 2NM for 250W nominal activities in non-CBD clothing in a summer jungle environment

NonCBD clothing comparison by SCENARIO_J for 250W activity in Jungle

◆ STDU+BA+LBE   △ Scorpion A   — C2005   ✕ C2005+10CFM

NonCBD clothing comparison by Simulink2NM for 250W activity in Jungle

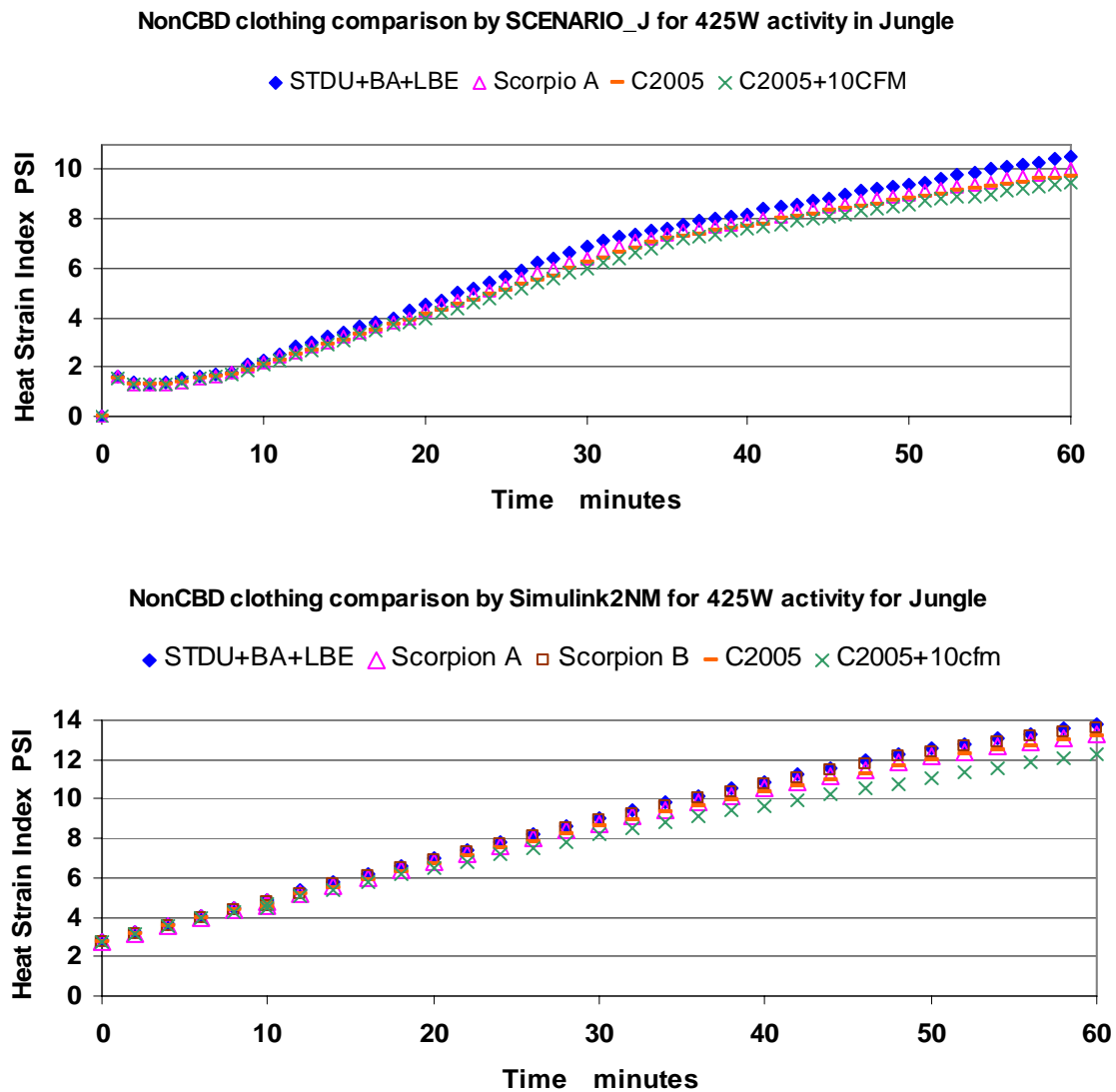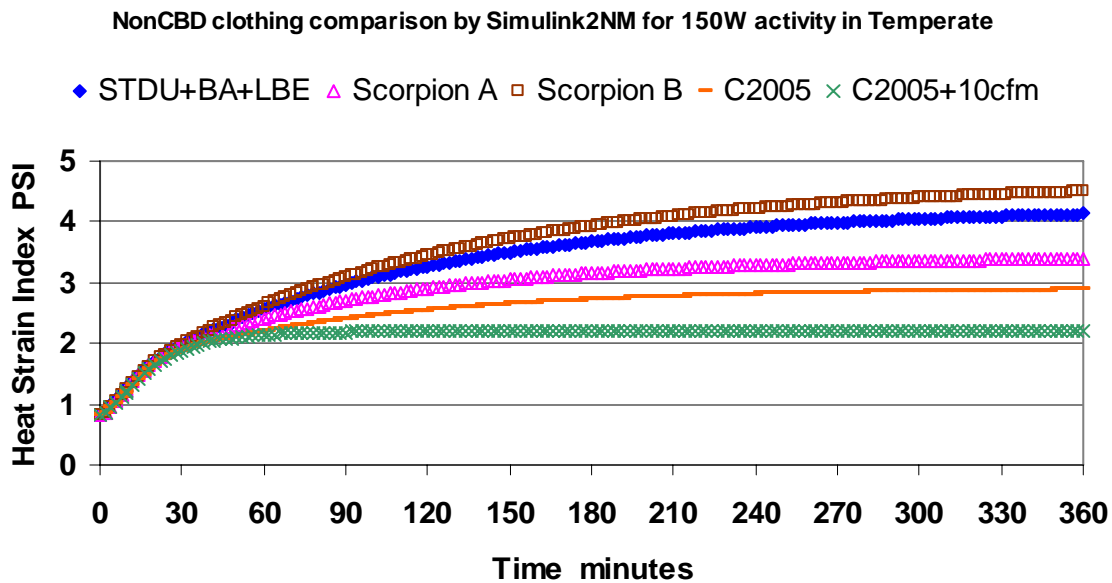◆ STDU+BA+LBE   △ Scorpion A   ☐ Scorpion B   — C2005   ✕ C2005+10cfm

Figure 10Jc. Physiological Strain Index (PSI) as predicted by SCENARIO_J and Simulink 2NM for 425W nominal activities in non-CBD clothing in a summer jungle environment
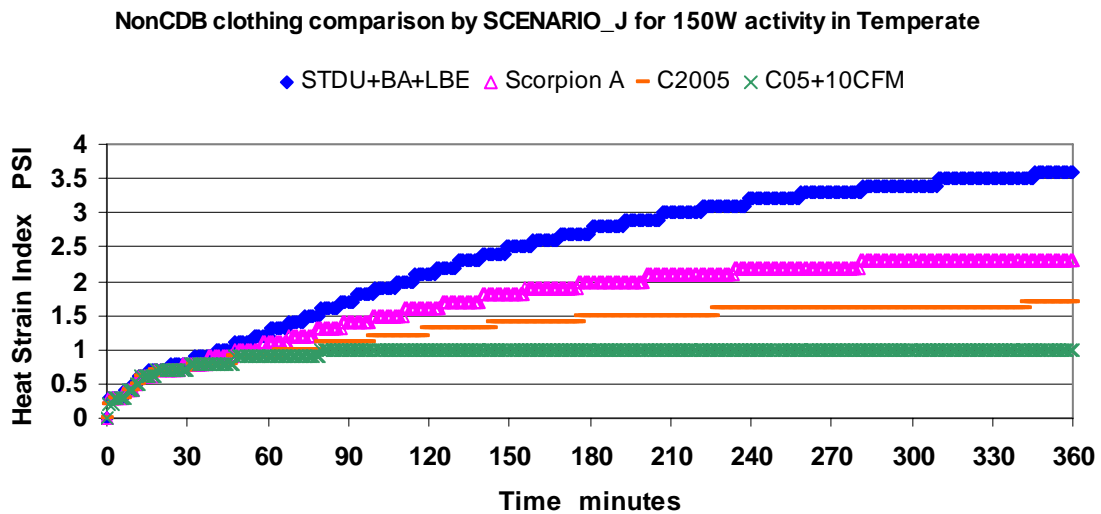

NonCBD clothing comparison by SCENARIO_J for 425W activity in Jungle

◆ STDU+BA+LBE △ Scorpio A ━ C2005 ✕ C2005+10CFM

NonCBD clothing comparison by Simulink2NM for 425W activity for Jungle

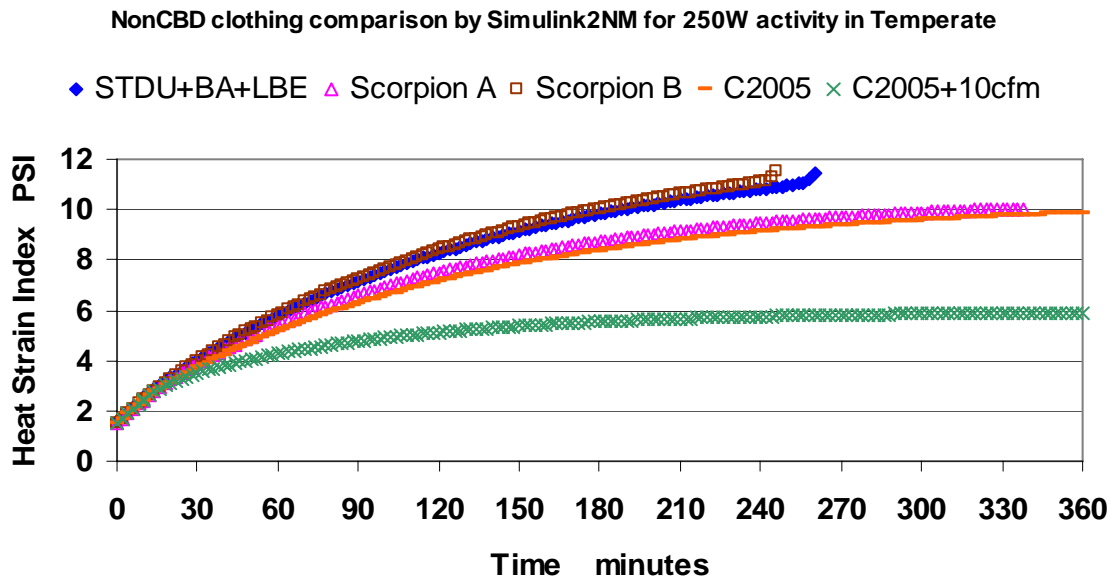◆ STDU+BA+LBE △ Scorpion A □ Scorpion B ━ C2005 ✕ C2005+10cfm

Figure 10Ta. Physiological Strain Index (PSI) as predicted by SCENARIO_J and Simulink 2NM for 150W nominal activities in non-CBD clothing in a summer temperate environment

NonCDB clothing comparison by SCENARIO_J for 150W activity in Temperate

◆ STDU+BA+LBE △ Scorpion A — C2005 ✕ C05+10CFM

NonCBD clothing comparison by Simulink2NM for 150W activity in Temperate

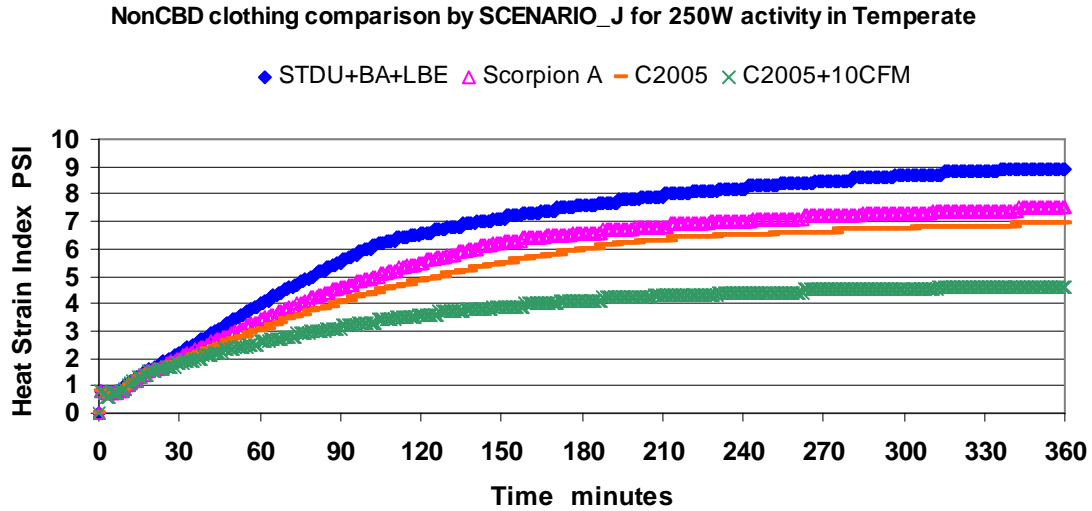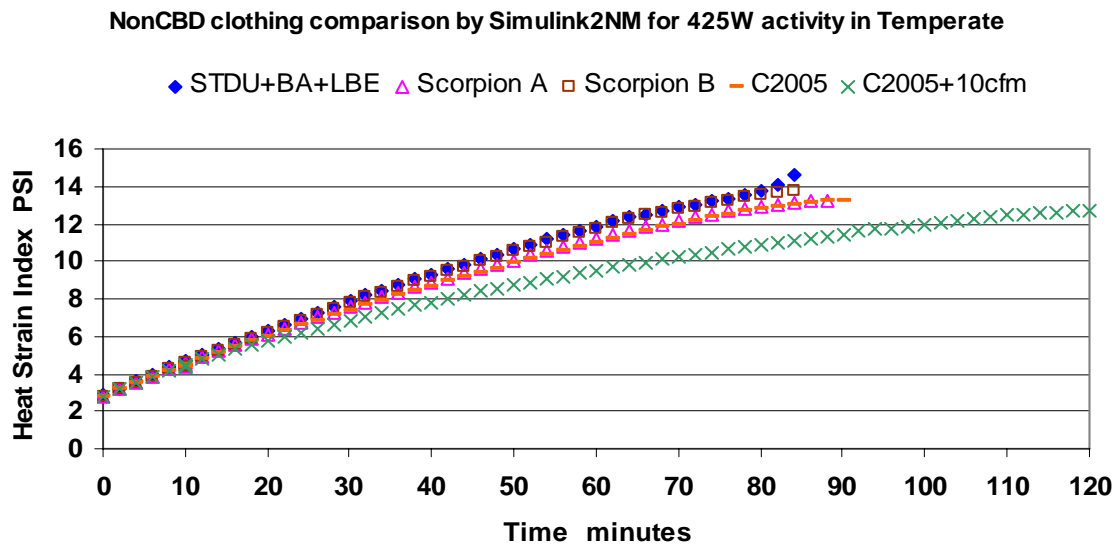◆ STDU+BA+LBE △ Scorpion A □ Scorpion B — C2005 ✕ C2005+10cfm

Figure 10Tb. Physiological Strain Index (PSI) as predicted by SCENARIO_J and Simulink 2NM for 250W nominal activities in non-CBD clothing in a summer temperate environment

NonCBD clothing comparison by SCENARIO_J for 250W activity in Temperate

◆ STDU+BA+LBE △ Scorpion A — C2005 ✕ C2005+10CFM

NonCBD clothing comparison by Simulink2NM for 250W activity in Temperate

◆ STDU+BA+LBE △ Scorpion A □ Scorpion B — C2005 ✕ C2005+10cfm

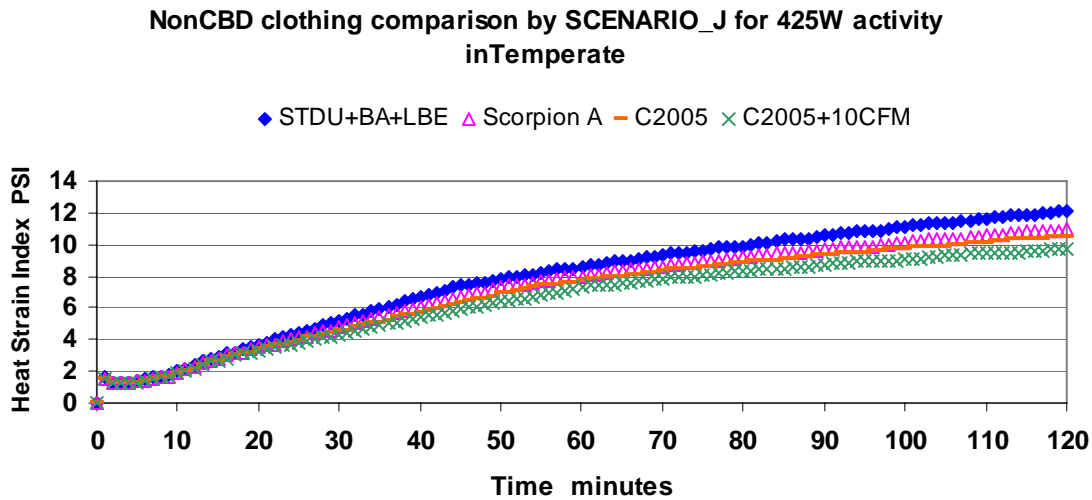# Figure 10Tc. Physiological Strain Index (PSI) as predicted by SCENARIO_J and Simulink 2NM for 425W nominal activities in non-CBD clothing in a summer temperate environment
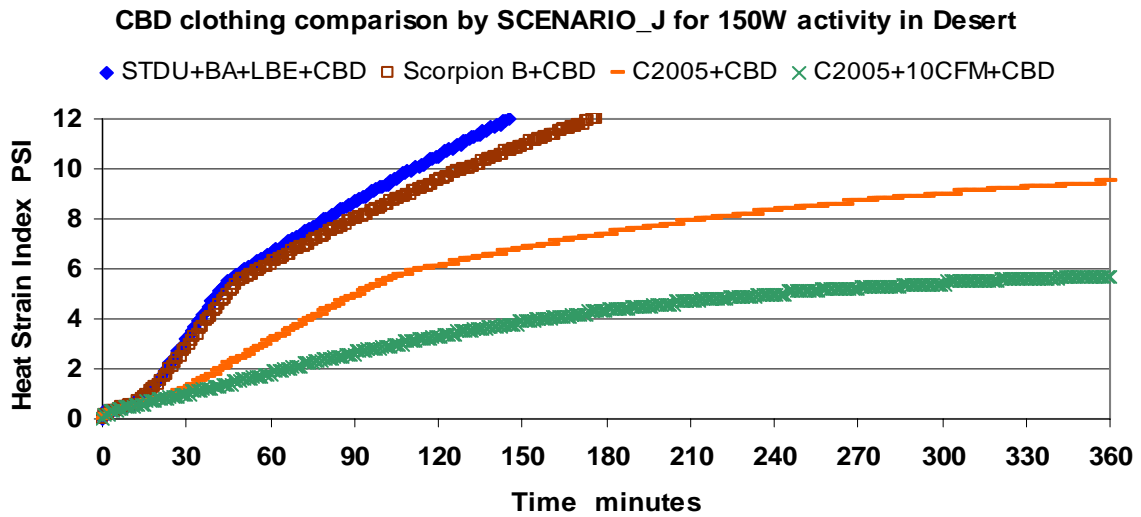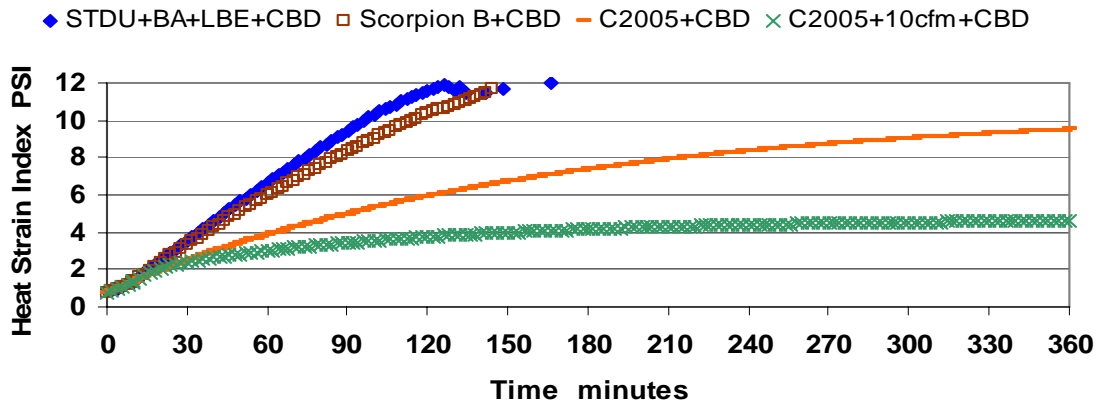
NonCBD clothing comparison by SCENARIO_J for 425W activity inTemperate

◆ STDU+BA+LBE △ Scorpion A ━ C2005 ✕ C2005+10CFM

NonCBD clothing comparison by Simulink2NM for 425W activity in Temperate

◆ STDU+BA+LBE △ Scorpion A ▢ Scorpion B ━ C2005 ✕ C2005+10cfm

Figure 11Da. Physiological Strain Index (PSI) as predicted by SCENARIO_J and Simulink 2NM for 150W nominal activities in CBD clothing in summer desert conditions

CBD clothing comparison by SCENARIO_J for 150W activity in Desert

◆ STDU+BA+LBE+CBD □ Scorpion B+CBD — C2005+CBD ✕ C2005+10CFM+CBD

CBDclothing comparison by Simulink2NM for 150W activity in Desert

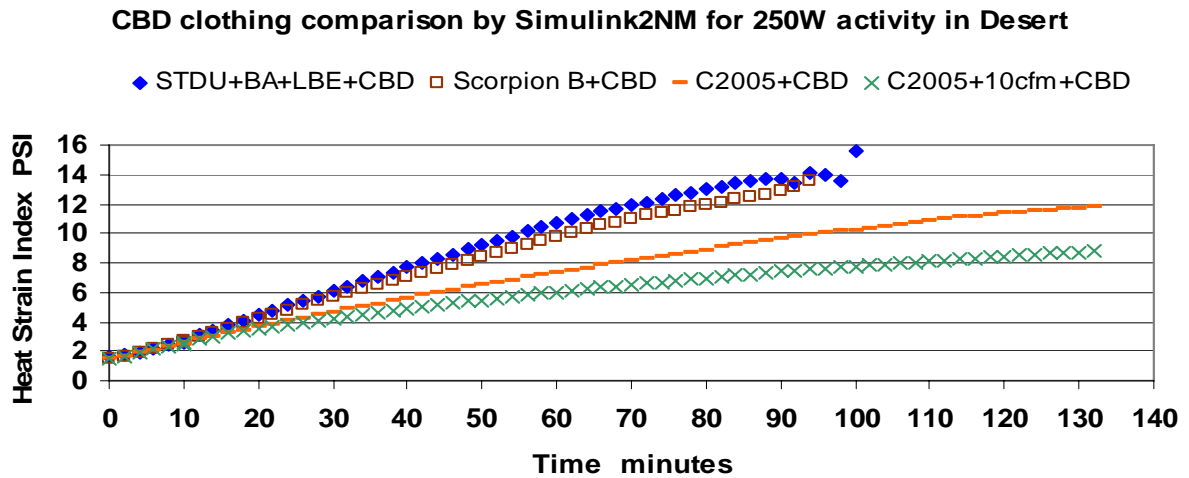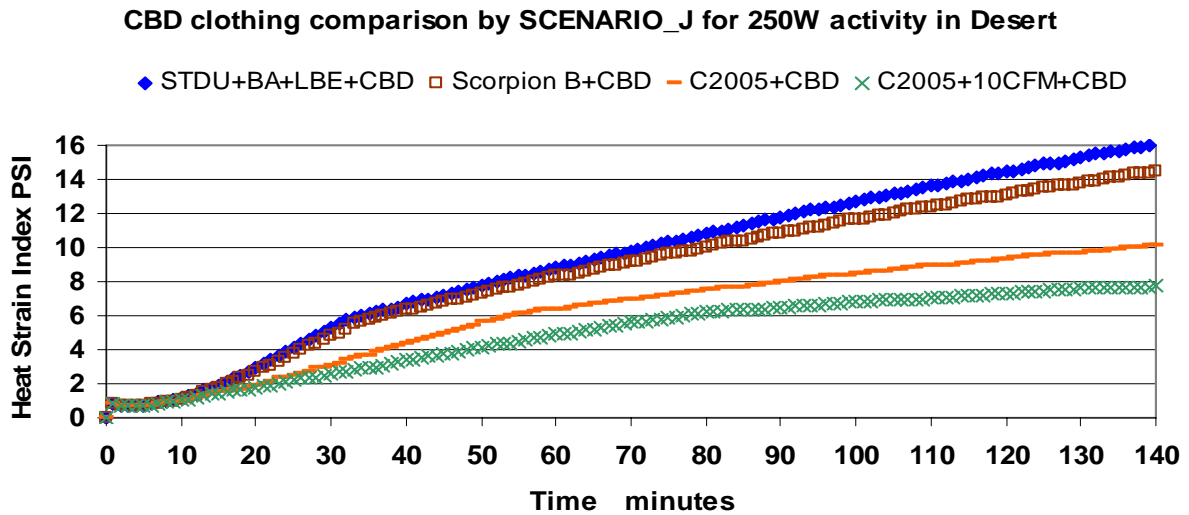◆ STDU+BA+LBE+CBD □ Scorpion B+CBD — C2005+CBD ✕ C2005+10cfm+CBD

Figure 11Db. Physiological Strain Index (PSI) as predicted by SCENARIO_J and Simulink 2NM for 250W nominal activities in CBD clothing in summer desert conditions

CBD clothing comparison by SCENARIO_J for 250W activity in Desert

◆ STDU+BA+LBE+CBD □ Scorpion B+CBD — C2005+CBD ✕ C2005+10CFM+CBD

CBD clothing comparison by Simulink2NM for 250W activity in Desert

◆ STDU+BA+LBE+CBD □ Scorpion B+CBD — C2005+CBD ✕ C2005+10cfm+CBD

Figure 11Dc. Physiological Strain Index (PSI) as predicted by SCENARIO_J and Simulink 2NM for 425W nominal activities in CBD clothing in summer desert conditions
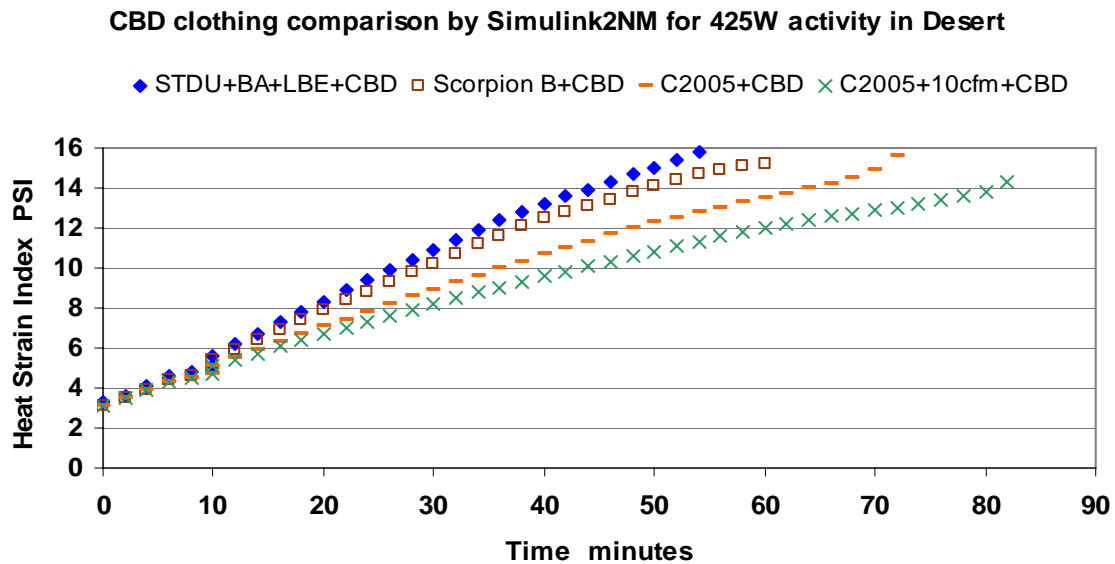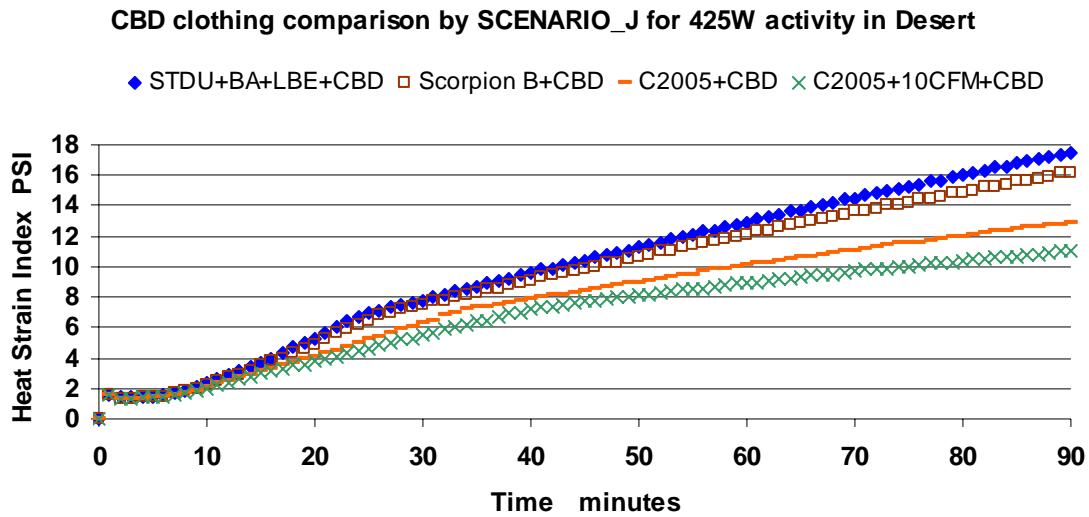
CBD clothing comparison by SCENARIO_J for 425W activity in Desert

◆ STDU+BA+LBE+CBD □ Scorpion B+CBD — C2005+CBD ✕ C2005+10CFM+CBD

CBD clothing comparison by Simulink2NM for 425W activity in Desert

◆ STDU+BA+LBE+CBD □ Scorpion B+CBD — C2005+CBD ✕ C2005+10cfm+CBD

Figure 11Ja. Physiological Strain Index (PSI) as predicted by SCENARIO_J and Simulink 2NM for 150W nominal activities in CBD clothing in summer jungle conditions
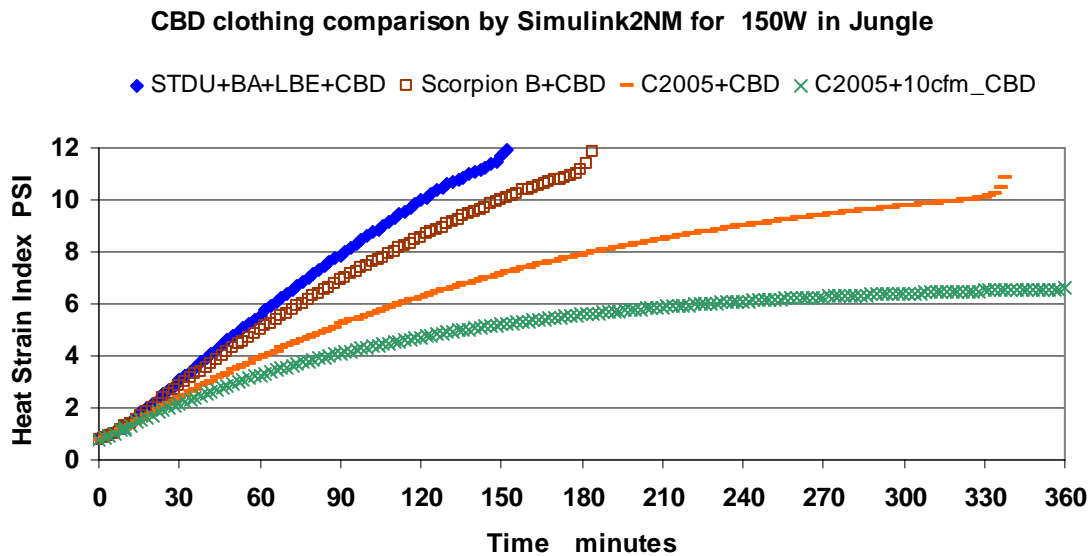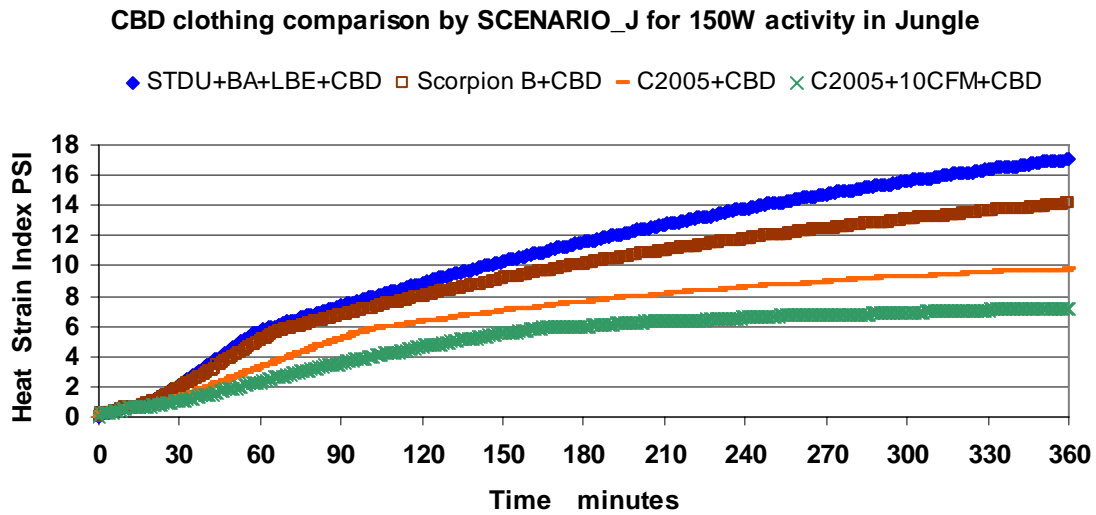
CBD clothing comparison by SCENARIO_J for 150W activity in Jungle

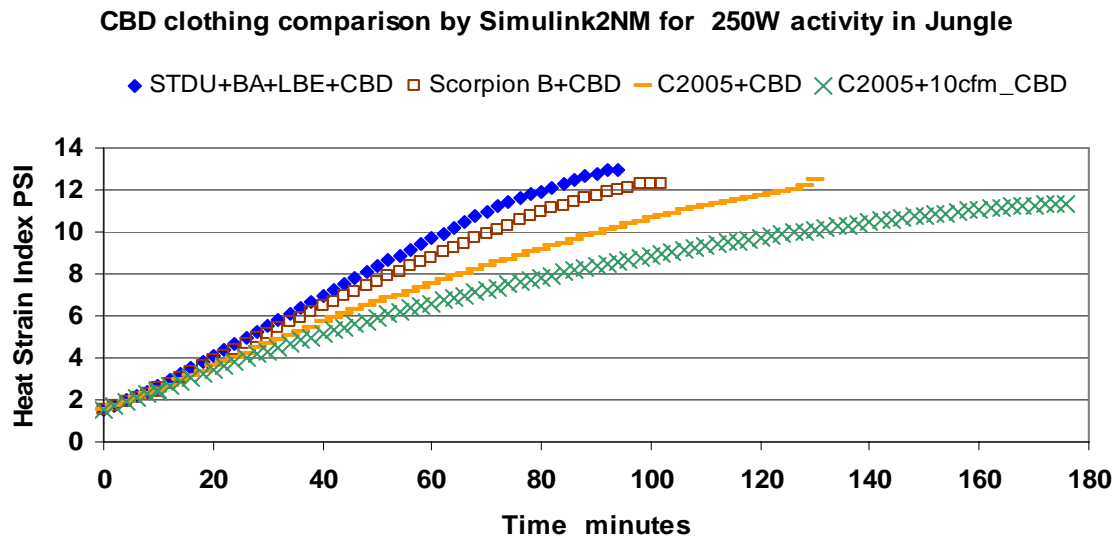**CBD clothing comparison by Simulink2NM for 150W in Jungle**

Figure 11Jb. Physiological Strain Index (PSI) as predicted by SCENARIO_J and Simulink 2NM for 250W nominal activities in CBD clothing in summer jungle conditions

CBD clothing comparison by SCENARIO_J for 250W activity in Jungle

◆ STDU+BA+LBE+CBD □ Scorpion B+CBD — C2005+CBD ✕ C2005+10CFM+CBD

CBD clothing comparison by Simulink2NM for 250W activity in Jungle

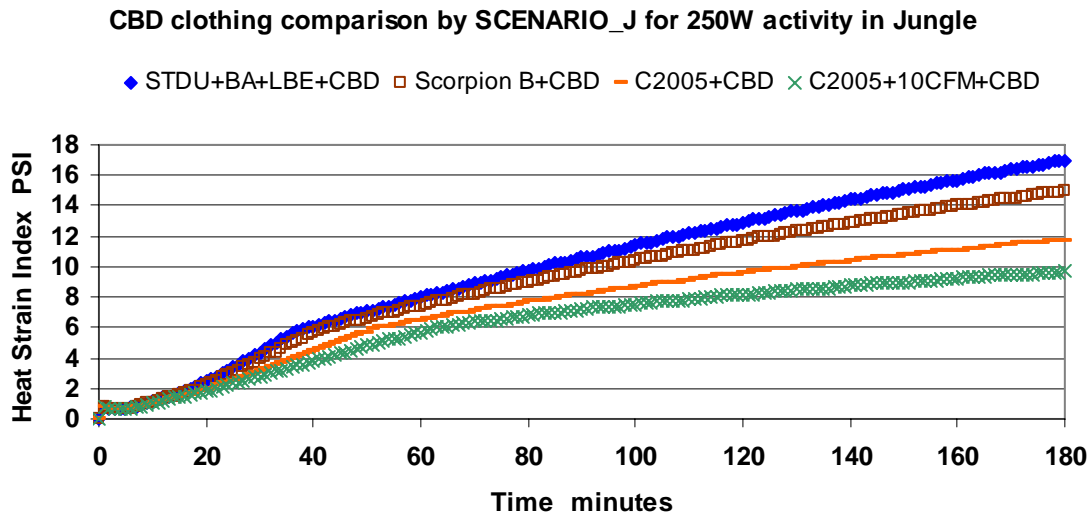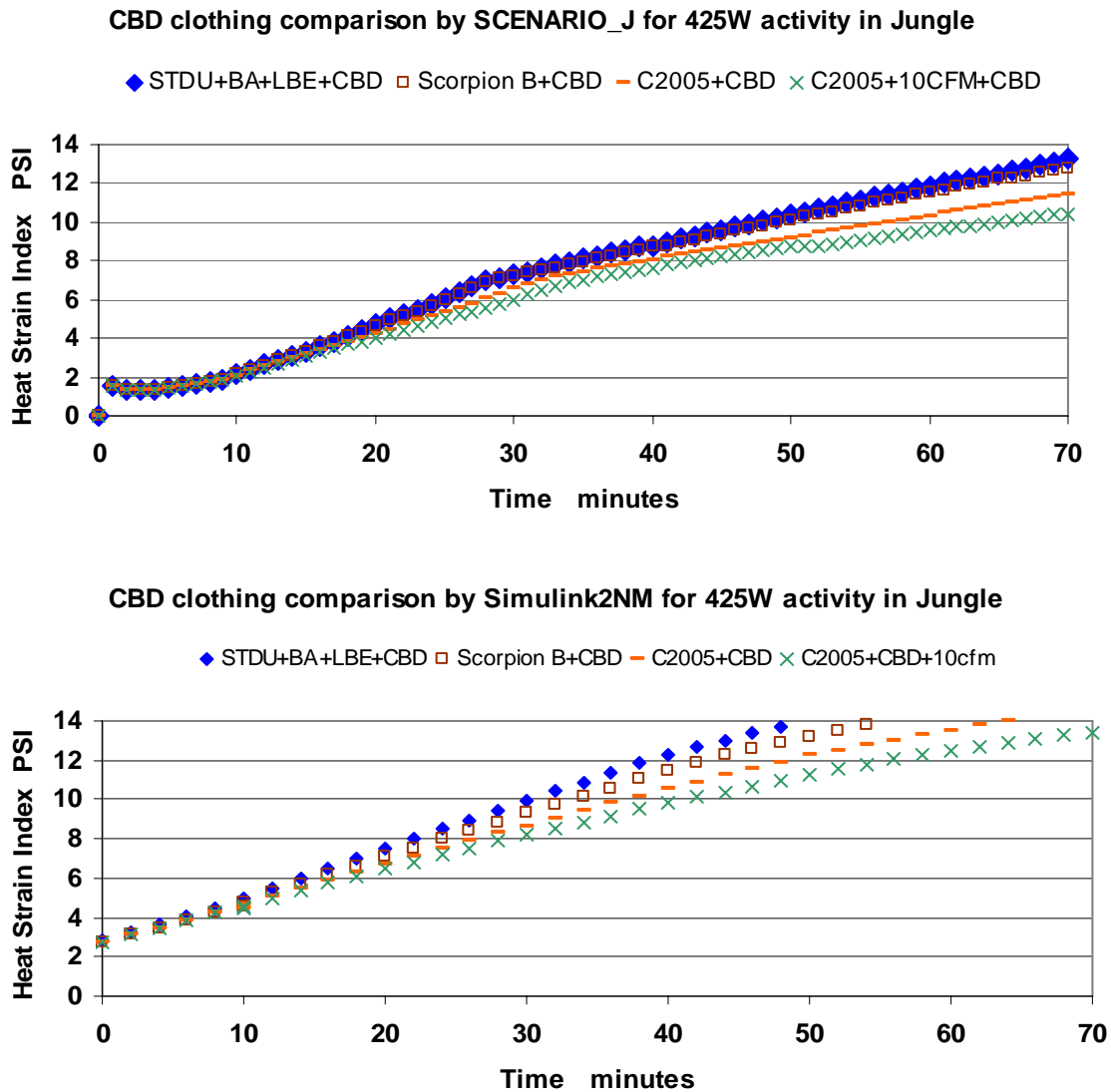◆ STDU+BA+LBE+CBD □ Scorpion B+CBD — C2005+CBD ✕ C2005+10cfm_CBD

Figure 11Jc. Physiological Strain Index (PSI) as predicted by SCENARIO_J and Simulink 2NM for 425W nominal activities in CBD clothing in summer jungle conditions

CBD clothing comparison by SCENARIO_J for 425W activity in Jungle

◆ STDU+BA+LBE+CBD □ Scorpion B+CBD — C2005+CBD × C2005+10CFM+CBD

CBD clothing comparison by Simulink2NM for 425W activity in Jungle

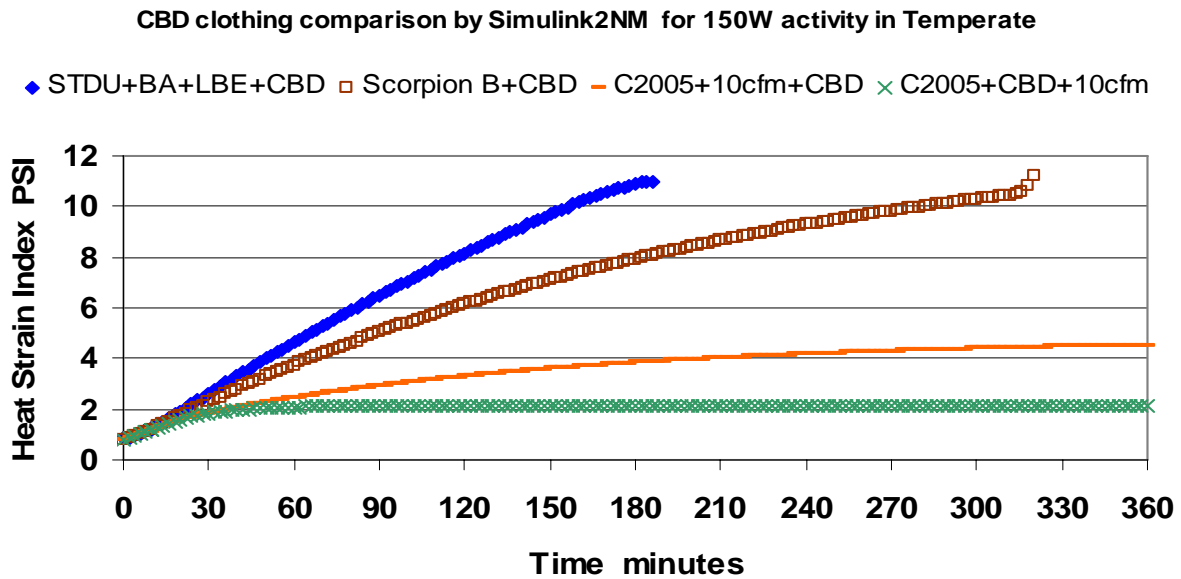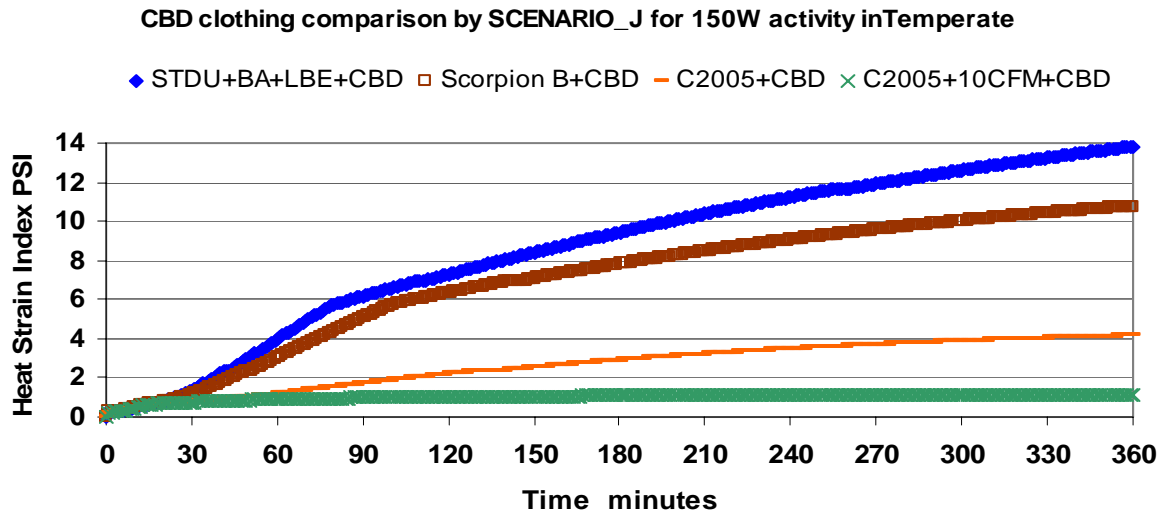◆ STDU+BA+LBE+CBD □ Scorpion B+CBD — C2005+CBD × C2005+CBD+10cfm

Figure 11Ta. Physiological Strain Index (PSI) as predicted by SCENARIO_J and Simulink 2NM for 150W nominal activities in CBD clothing in summer temperate conditions

CBD clothing comparison by SCENARIO_J for 150W activity inTemperate

CBD clothing comparison by Simulink2NM for 150W activity in Temperate

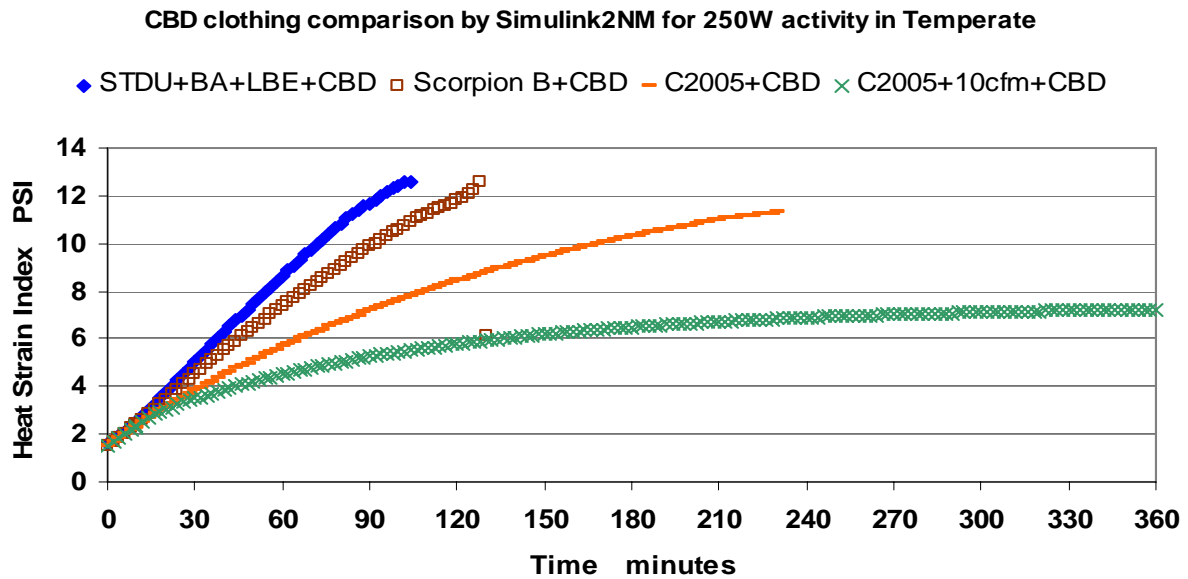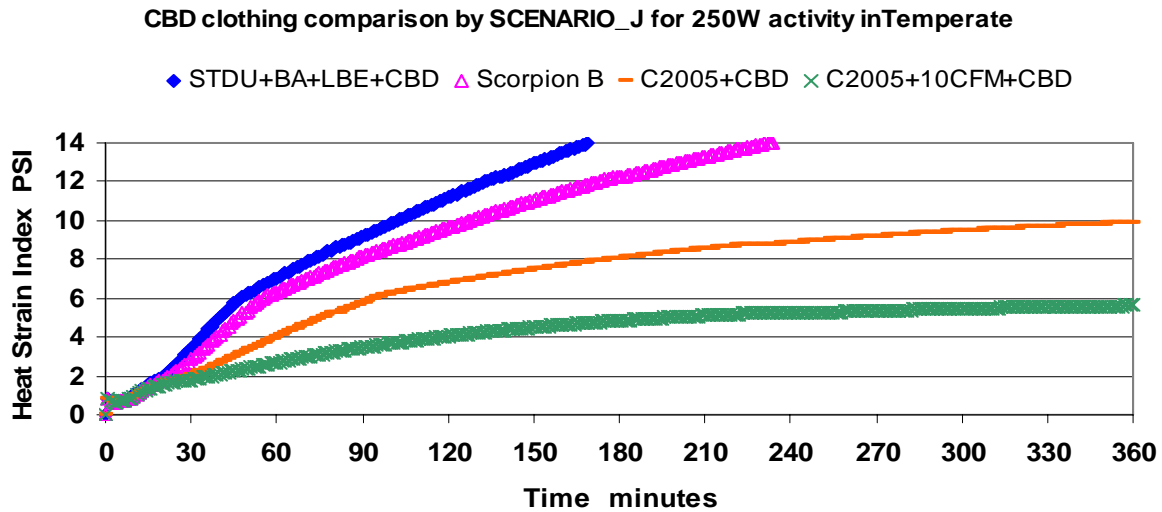**Figure 11Tb. Physiological Strain Index (PSI) as predicted by SCENARIO_J and Simulink 2NM for 250W nominal activities in CBD clothing in summer temperate conditions**

CBD clothing comparison by SCENARIO_J for 250W activity inTemperate

◆ STDU+BA+LBE+CBD △ Scorpion B ─ C2005+CBD ✕ C2005+10CFM+CBD

CBD clothing comparison by Simulink2NM for 250W activity in Temperate

◆ STDU+BA+LBE+CBD ☐ Scorpion B+CBD ─ C2005+CBD ✕ C2005+10cfm+CBD

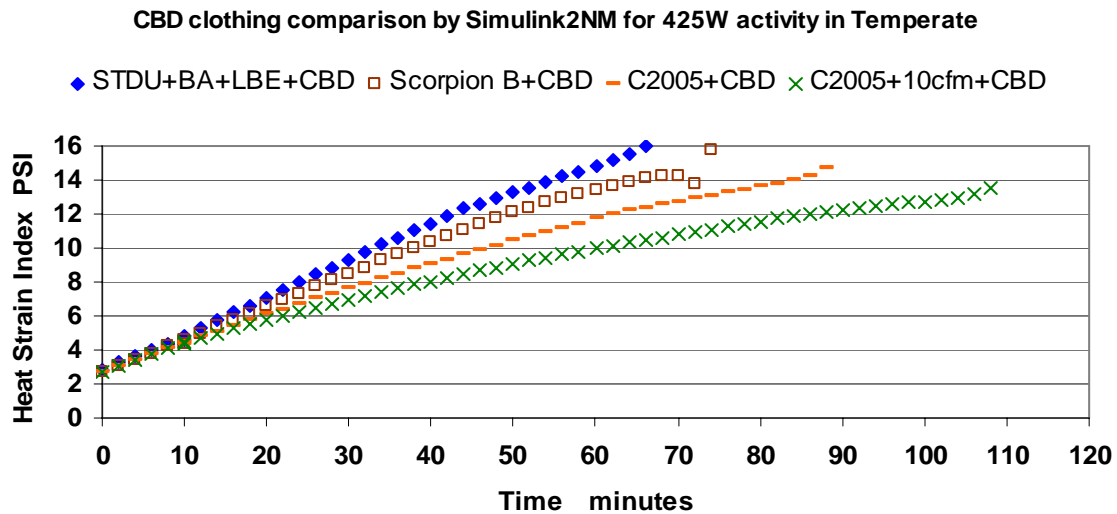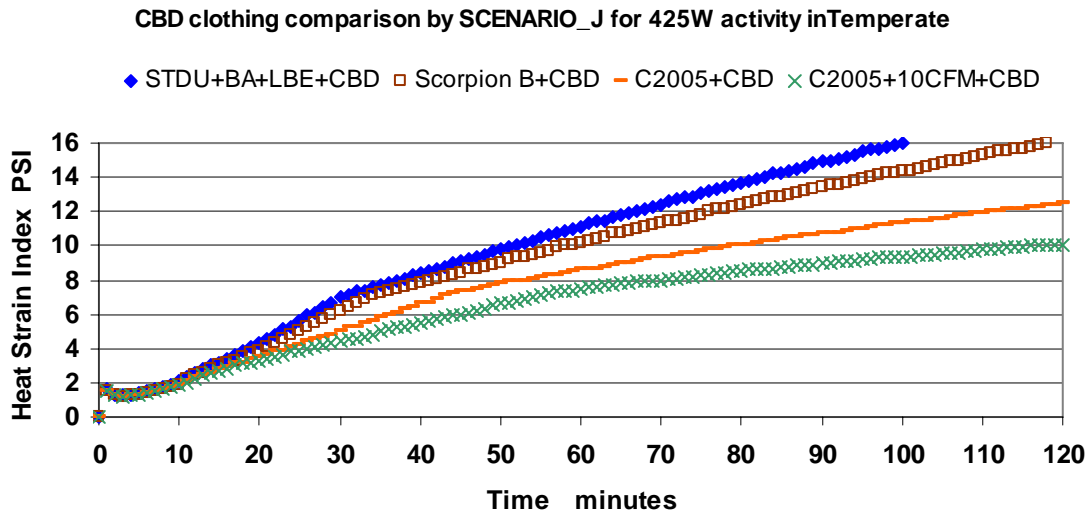# Figure 11Tc. Physiological Strain Index (PSI) as predicted by SCENARIO_J and Simulink 2NM for 425W nominal activities in CBD clothing in summer temperate conditions

CBD clothing comparison by SCENARIO_J for 425W activity inTemperate

◆ STDU+BA+LBE+CBD □ Scorpion B+CBD — C2005+CBD ✕ C2005+10CFM+CBD

CBD clothing comparison by Simulink2NM for 425W activity in Temperate

◆ STDU+BA+LBE+CBD □ Scorpion B+CBD — C2005+CBD ✕ C2005+10cfm+CBD

CONCLUSIONS

Soldier responses wearing various Scorpion prototype designs were tested and compared to responses in the current standard uniform system. The comparison tests were done by computer simulation of Soldiers with three different and respected independent thermal physiological response models. The responses to a given condition and activity were a little different for each model but the response trends and conclusions were very similar. This is somewhat like what one would expect from testing the clothing systems on three different Soldiers. The response differences between the models are greatest at the 425W activity levels with the Simulink2NM model showing the fastest and or greatest response to the conditions. This 425W level is close to the "self-paced" activity level and soldier duty-type activities. Because PSI combines thermal and cardiovascular strain into a single index, PSI may be good metric to quantify and compare human responses of future clothing designs for hot environments.

The summer desert, jungle, and temperate conditions of the tests have air temperatures close to or greater than skin temperature which reduces dry heat loss to about zero and even to a dry heat gain for the desert. Thus the Soldier depends almost completely on the evaporation of sweat for thermoregulation and survival. And the results show that sweat evaporation has progressively improved with the prototype designs. Overall the incremental clothing design changes have resulted in corresponding human response benefits for the conditions tested. That is, less elevated body temperatures, longer exposure times, lower HR and physiological strain, and less water loss. Some of the benefits result from clothing weight reductions, permitting the Soldier to move about with less metabolic energy expenditure. The results also clearly show the value and effectiveness of clothing ventilation when needed in warm situations.

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